THE VALUE OF WATER AS AN ECONOMIC RESOURCE IN THE VAAL RIVER CATCHMENT

BY

GREENGROWTH STRATEGIES cc

Report to the Water Research Commission on the Project "The Value of Water as an Economic Resource in the Vaal River Catchment"

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December 2003

WRC Report No: 990/1/03
ISBN No: 1-77005-126-0

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ACKNOWLEDGEMENTS IN FINAL REPORT

The research in this report emanated from a project funded by the Water Research Commission and entitled:

"THE VALUE OF WATER AS AN ECONOMIC RESOURCE IN THE VAAL RIVER CATCHMENT"

The Steering Committee responsible for this project consisted of the following persons:

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The project was only possible because of the active co-operation of members of the Steering Committee and their direct associates who gave generously of their time, provided information, encouragement and advice.

The project team would like to thank the Water Research Commission for funding the project and specifically for the tolerance and understanding shown when the project proved to be more comprehensive than was originally envisaged. The guidance and support provided by the chairman of the Steering Committee, Dr G.R. Backeberg, is highly valued.

The research team would also like to acknowledge the contribution of the following individuals:

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EXECUTIVE SUMMARY

Water is a scarce resource in South Africa and future economic development may be increasingly restricted if water is allocated and used inefficiently. Water supply has traditionally been augmented in line with growing demand. However, in view of the increasing shortage of new supply options, water demand management and specifically the optimization of water distribution is coming to be of increasing importance. At present, national policy is moving towards water demand management. Thus there is a growing need to understand the economic features of water demand areas in South Africa.

In addressing the orderly management of water resources, the Water Research Commission (WRC) commissioned a research project in 1998 to determine the value of water in selected catchments of South Africa. The WRC put the research project out on tender.

In the invitation for tenders, the following catchments or sub-catchments were identified as possible case studies, namely:

- The Great Letaba River;
- The Berg River;
- The Great Fish/Sundays River; and
- The Vaal River.

The tender to determine the value of water as an economic resource in the Vaal River catchment was awarded to Greengrowth Strategies cc.

In broad terms the objectives of this research initiative according to the tender document were stated as follows:

1. Determine the water balance and prevailing competition for water resources in the catchment.

2. Derive a demand schedule curve for water for important water use sectors.

3. Quantify the value of water resources at current levels of water use.

4. Compare the economic value with full economic costs (i.e. supply, opportunity and external costs, if applicable) as well as current water tariffs, and assess the incidence and nature of temporary or permanent transfers of water rights already occurring.

5. Explore a variety of scenarios and estimate the changes in the value and price of water resources through appropriate modelling, when negotiated and lawful transfers of rights to available water resources take place within or between existing uses.

In order to address these objectives, it was necessary that proper Natural Resource Accounts be drawn up for the Vaal River system, for the period 1980-1998. Natural Resource Accounts, which supplement a country's traditional national economic accounting system, are designed to assist in the analysis and design of sustainable development strategies through the optimization of natural resource utilization over the long term.

For development planning purposes, the geographic extent of the Vaal River system is normally defined from a water use point of view and this practice has been followed in this study. This differs from the practice in other areas where planning takes place strictly within the boundaries of catchments. An example of this is that the Tshwane Metropole was included in the study area, because most of the water it uses is transferred from the Vaal River system to it, although it actually is in the Crocodile catchment.

Due to the significant difference in the type of water use in the study area, the river was divided into two sections for purposes of this study, namely the "Upper Vaal" and the "Middle Vaal". The Upper Vaal user area as defined for this study closely corresponds to the Upper Vaal catchment, except for the inclusion of the Crocodile catchment. The Middle Vaal study area includes the whole Middle Vaal catchment as well as a portion of the Lower Vaal catchment. The water use of the Upper Vaal is mainly industrial and domestic whilst that of the Middle Vaal is mainly agricultural.

The supply of water was sub-divided into surface water and ground water. The main water use sectors are:

- Municipal use (subdivided into Household, Light Industry and Parks)
- Irrigation use
- Afforestation use
- Electricity use and
- Heavy Industry use.

For modelling purposes, a system dynamics model of the Vaal River system was developed. STELLA, a software package for developing system dynamics computer models, was used to model a variety of complex systems by attempting to understand the underlying relationships between the different parts of the system. For the purpose of this study, the total system has been consolidated into two "dummy dams" represented as the Upper and Middle Vaal systems. In practice these dummy dams represent the Vaal and Bloemhof dams respectively.

Important aspects pertaining to the historic water balance are:

- That the utilization level increased from 53.8 % in 1980 to 75.6 % in 1998 for the Upper Vaal River system even though it fluctuated over this period.
- For the Middle Vaal River system the water utilization level increased from 175.8 % in 1980 to 204.3 % in 1998. The increase is due to a usage increase without an equivalent increase in water supply. However, in practice, water releases from the Vaal Dam compensate for this deficit.
- The water utilization level within the total Vaal River system increased from 71.1 % in 1980 to 94.2 % in 1998.
- As far as the composition of water supply is concerned, transfers in exhibit an increase from 13 % in 1984 to 16 % in 1998. After 1998 which falls outside the time period analysed here, the percentage will increase considerably because of the introduction of the Lesotho Highlands Scheme.
- As far as the composition of water use in the Vaal River is concerned, irrigation is still the main user of water as its water utilization level stood at 35 % of total water use in 1998. In 1980 this utilization level stood at 37 % of total water use which implies a slight decrease over the period. The other important uses are light and heavy industries with 22 % in 1998 whereas in 1980 this figure was 20 %. Another notable trend is that water use for households has remained at 18 % of total use.

The economic value of water for the various users is calculated by estimating their demand schedules. The following procedures were used to derive demand schedules for the various use categories:

- For households a cross sectional analysis was done and the reaction of different users to different tariffs (tariff was used as a proxy for price) at the same point in time was investigated. A relationship was determined between consumption and tariff data for different municipalities. An advantage of this method is that many factors influencing water consumption can be simultaneously analysed through multi-regression analysis.
- In the case of irrigation use the so-called "budget approach" was used. It was decided to take the Vaalharts area as a sample for the total study area.
- For industrial use the budget approach was also applied to the various industries in South Africa. The information base for the calculation was an input-output table, which reflects the value of water per sector in relation to the sector's total production cost. In theory it could be stated that the water tariff could be increased up to the point where the industry does not make profits anymore. A problem associated with this approach is that the water tariff can be increased to absorb all the profits excluding a normal profit (normal profit already forms part of the total cost of the budget approach). In practice certain industries can easily relocate to other industrial locations in South Africa, where water tariffs are more

attractive. Therefore theory and practice are not compatible. For purposes of this study, it was assumed that industries will only be willing to pay more for water in the Vaal River system area if they derive a locational advantage from remaining there.

- As far as electricity use is concerned, a demand schedule was obtained by distinguishing between two cooling systems in power generation stations. In South Africa electricity is mainly generated by coal based power generation stations. Two alternative cooling systems are used in these power stations, namely wet and dry cooling systems. A wet cooling system uses much more water than a dry cooling system to generate the same amount of electricity. In a wet cooling system ± 2.23 *l* of water is used to generate 1 kWh of electricity compared with the 0.22 *l* of water per kWh of electricity in a dry cooled system. However, building a dry cooling system is much more costly than a wet one. The running costs of a dry cooling system are also slightly higher.

By applying the demand schedules above, the economic value of water for the total Vaal River system was calculated to be R13,3 billion for 1998. Of this total the contribution of the Upper Vaal is R11,6 billion (87 %) and that of the Middle Vaal R1,7 billion (13 %). It is important to note that this is a flow variable, i.e. it is a recurrent value.

Regarding the sectoral contribution to economic value, municipal use is by far the most prominent sector, contributing 81 % in 1998 in the Upper Vaal. In the Middle Vaal municipal use in terms of economic value is also dominant (93 %), although the most water used (physical units) is by irrigation.

Concerning the analysis of cost and revenues, it is important to note that over the last 10 years the Department of Water Affairs and Forestry (DWAF) has gradually phased in the policy that a specific catchment's revenue should pay for the delivery cost of the relevant water. One of the designated catchments in terms of this policy was the Vaal River and the policy resulted in revenue received from water tariffs being more than the delivery cost of the water including the cost of major water schemes. The total revenue for 1998 was calculated to be in the order of R1,682 billion, compared to a delivery cost of R1,547 billion. This implies an over recovery of R125 million.

The last objective of the study was to test the reliability of the model, by generating illustrative water management scenarios. Scenarios explored included different climatic conditions and various views on population growth, specifically taking into account the impact of AIDS. Although some of the assumptions are probably unrealistic, interesting conclusions could be derived from these scenarios.

An example of this is the impact of a dry weather cycle, the main effect of which will be that there will not be sufficient water for usage over the modelling period. In a real market situation the price of water will increase and selling of water will take place. The use sectors with low income yields will trade their water rights to other users with higher yields rather than proceed with their current activities. The following aspects of the dry cycle scenario are of importance:

- The price of water (proxied by tariff) will increase drastically by about 35 %.
- The average use of water has to drop by 14 % to conform with the supply conditions.
- The economic value of water will drop by approximately 12 %. This is mainly due to the fact that water shortages will be reflected mostly in the irrigation and household use sectors.
- Although less water will be sold, the revenue generated from the selling of bulk water will increase by 5,5 %. This can be attributed to the increase of 35 % in the water price.
- The consumption in terms of volumes for Industries and Electricity remains constant, although their percentage shares increase slightly.

In conclusion, it can be stated that the objectives set in the terms of reference have been met reasonably successfully, and a large amount of new information has been made available. In particular, a very significant contribution has been made to the development of Natural Resource Accounts in South Africa. However, it must be emphasized that the expectations with which the project team began the study met with some disappointment. In many cases, the first-choice data that the team had expected to be available was of such poor quality that alternative methods of addressing the objectives had to be found. The negative aspect of this is that it must be accepted that many databases in South Africa are currently in a state that does not support sophisticated economic analysis. More positively, this study has laid a foundation on which other studies of this nature can build, although it must be accepted that their results, like those of the present study, will be somewhat approximate in nature.

The model that has been constructed in this study must be viewed as a "living" one. Its usefulness lies much more in the future use that will be made of it than in the history of its development that has been reported in this present document. The first recommendation of this report is therefore that use of the model should be encouraged. Another recommendation of the project team is that water authorities in South Africa should take stock of the data that they may require in future to do their jobs, in particular in the light of changing water management requirements.

They need to ask whether the data they will need is being collected and maintained in an accessible format. If this is not the case, they need to take steps to remedy the situation.

MAP 1: THE VAAL RIVER CATCHMENT

LIST OF TABLES, MAPS, FIGURES, CHARTS & GRAPHS

Map No.

Figure No.

Chart No.

Graph No.

ACRONYMS

THE VALUE OF WATER AS AN ECONOMIC RESOURCE IN THE VAAL RIVER SYSTEM

CBA	-	Cost-Benefit Analysis
DBSA	-	Development Bank of Southern Africa
DWAF	-	Department of Water Affairs and Forestry
EVIEWS	-	A computer software package for econometric analyses
EXCEL	-	A spreadsheet software computer package
GDP	-	Gross Domestic Product
GGP	-	Gross Geographic Product
NFI	-	Net Farming Income
NI	-	Net Income
NRA	-	Natural Resource Accounting
OLS	-	Ordinary Least Squares
RSA	-	Republic of South Africa
SAM	-	Social Accounting Matrix
SNA	-	System of National Accounts
SSA	-	Statistics South Africa
STELLA	-	A software package for developing a system dynamics computer model
UK	-	United Kingdom
UN	-	United Nations
WfW	-	Working for Water Programme of DWAF
WMA	-	Water Management Area
WRA	-	Water Resource Accounts
WRC	-	Water Research Commission
WUA	-	Water Use Authority

LIST OF DEFINITIONS

Demand schedule (curve):	A curve depicting the relationship between a dependent variable (water use) and an independent variable (price, where price is proxied by tariff).
Efficiency of water use:	Efficient water use occurs when the marginal revenue derived as a result of delivering water to a sector is greater than the marginal cost of delivering water to that sector.
Elasticity:	This refers to the price elasticity of demand for water. This concept measures the proportional change in the quantity of water demanded as a result of a proportional change in the water tariff.
GDP:	The measure of the total gross value added (total value of the goods and services produced within the country less raw materials and other goods and services consumed during the production process) in all resident producing units.
Input/Output table:	This is a matrix indicating the sectoral interrelationships in an economy. It forms the nucleus of any model that analyses and projects the economy on a sector-to-sector basis.
Lower income level:	This income level refer to incomes below R26 900 p.a. (calculated from a SAM compiled by Conningarth Economists) (2002).
NFI:	Net farm income is defined as gross product margins minus farm fixed costs.
NI:	Net income of farmers is obtained by subtracting a management fee and capital yield from net farm income (NFI).
Raw water:	Water in a dam or river before it is purified or bulk distributed.

SAM:	A social accounting matrix which depicts linkages that exist between all the different roleplayers in the economy.
Study Area:	For purposes of this study the Vaal River system was defined from a user perspective (i.e. it includes all geographic areas that use water from the system). This area was further subdivided into an Upper Vaal user area and a Middle Vaal user area. The total study area incorporates almost the whole Vaal River catchment. It deviates, however, in the sense that a portion of the Lower Vaal catchment is excluded, whilst the Crocodile catchment was added to the Upper catchment (also see section 2.1.3 for more detail).
Upper-Middle income level:	This income level refers to incomes equal to or above R26 900 p.a. (calculated from a SAM compiled by Conningarth Economists) (2002).
Value of water:	The maximum amount a user would be willing to pay for the use of water.

CHAPTER ONE

BACKGROUND

1.1 ORIGIN OF THE PRESENT PROJECT

Water is a scarce resource in South Africa and future economic development may be increasingly restricted if water is allocated and used inefficiently. Water supply has traditionally been augmented in line with growing demand; however, in view of the increasing shortage of new supply options, water demand management and specifically the optimization of water distribution is coming to be of increasing importance. At present, national policy is moving towards water demand management through administrative intervention. Thus there is a growing need to understand the economic features of water demand management areas in South Africa. This study aims to make a contribution to that understanding.

Each economic sector has its own justification for the utilization of water. However, an increase in one sector's share of water will result in an opportunity foregone by another sector. Thus, it is useful to understand how a market would allocate the water in the Vaal River system by assessing the economic advantages of the use of water resources by the various economic sectors. This can be done by obtaining the information needed in a structured way through Natural Resource Accounting (NRA). In turn this would make it possible to rationally negotiate the allocation of water in order to maximise total economic and social development.

National Resource Accounts, which supplement a country's traditional national economic accounting system, are designed to assist in the analysis and design of sustainable development strategies through the optimization of natural resource utilization over the long term.

1.2 RESEARCH INITIATIVE

In addressing the efficient management of water resources, the Water Research Commission (WRC) commissioned a research project in 1998 to determine the value of water in selected catchments of South Africa. The WRC put the research project out to tender.

In the invitation for tenders, the following catchments or sub-catchments were identified as possible case studies, namely:

- The Great Letaba River;
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The tender to determine the value of water as an economic resource for the Vaal River catchment was awarded to Greengrowth Strategies cc.

The objectives of this research initiative according to the tender document were stated as follows:

1. Determine the water balance and prevailing competition for water resources in the catchments.

2. Derive a demand schedule for water for important water use sectors.

3. Quantify the value of water resources at current levels of water use, with due consideration of the following factors:

    - prevailing and proposed water policies, water rights law and legislation;
    - intensity of water use and relative importance of water inputs in the production cycle;
    - level of household income, community participation and willingness to pay;
    - economic linkages and multiplier effects in each water use sector;
    - value of water to users, adjustment for societal objectives, net benefit from indirect uses and from return flows;
    - degree of technological development, reliability of supply and water quality concerns.

4. Compare the economic value with full economic costs (i.e. supply, opportunity and external costs, if applicable) as well as current water tariffs, and assess the incidence and nature of temporary or permanent transfers of water rights already occurring.

5. Explore a variety of scenarios and estimate the changes in the value and tariff of water resources through appropriate modelling, when negotiated

and lawful transfers of rights to available water resources take place within or between existing uses.

Given the overall scarcity of water in South Africa, it is important for the country's economic well-being that these objectives should be met. However, as will become clear in the report, the attempt to meet the objectives was significantly constrained by the unavailability of data of good quality. This situation deserves the attention of relevant authorities.

1.3 OBJECTIVES

It follows from the previous section that the essence of the project is to develop a model of the economic forces of supply and demand that are present in the Vaal River catchment, in order to examine the consequences that would result if water in this catchment were to be transferred between water users. In turn, this simulated water supply and demand will generate economically efficient allocations of water to serve as guidelines to decision makers.

There are two prerequisites to a study of this nature, namely:

a) a model structure must be created, and
b) the model must be populated with data.

a) **Creating the model structure**

A system dynamics model was developed to simulate a market clearing process, taking into account supply and use structures.

b) **Populating the model with data**

For the model to generate reliable results, it should be based on a consistent data base where demand equals economic usage[1)]. The consequence of this is that a fairly complete natural resource accounting system had to be compiled for the Vaal River system as part of this study.

In compiling these accounts the following objectives listed in section 1.2 above were achieved:

1. The water balance for the historical period 1980-1998 was determined.
2. Demand schedules for water for the important water use sectors were derived.
3. The economic value of water was determined.

1) Usage takes into account the residual (water entering the sea) plus evaporation.

4. The delivery cost, tariffs and subsidies were estimated.

The model, the data and the achievement of these four objectives are discussed in Chapters 2 to 5 of this report.

The remaining objective of the study is to explore a variety of scenarios and estimate the changes in the value and tariff of water resources that result from changes in supply or demand. This is discussed in Chapter 6 of the report.

1.4 THEORY AND PRACTICE OF NATURAL RESOURCE ACCOUNTING

Although this was not stated explicitly in its original terms of reference, this study relies heavily on the principles of National Resource Accounting (especially physical resource accounting). In fact, a major part of this study has been devoted to compiling, for the first time, detailed accounts of the Vaal River system[2]. It is thus useful to take a few pages to contextualize the study in this way. Accordingly, in this chapter the theoretical background to resource accounting in general and water resource accounting in particular will be discussed briefly.

1.4.1 <u>Why Include the Environment in the National Accounts</u>

The United Nations[3] (UN) explains the relationship between the environment and national accounting as practiced 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, focussing 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

[2] It will be explained in the following chapter that, due to the nature of the terms of reference for this study, only some accounts have been compiled: specifically, accounts for water flows, but not stocks, have been drawn up.

[3] United Nations, 1999, Integrated Environmental and Economic Accounting, Operational Manual.

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[4)] 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 fuelwood 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.

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4) Lange, GM & Hassan, RM (1999), Natural Resource Accounting as a Tool for Sustainable Macroeconomic Policy: Application in Southern Africa: IUCN Policy Brief.

- **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 (See Asheim, (2000))[5] three policy uses of National Resource Accounts have been mentioned:

(1) 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?);
(2) Measurement of sustainable income for the purpose of judging whether actual development is sustainable; or
(3) Measurement of the desirability of policy changes.

1.4.2 <u>International Developments Regarding Natural Resource Accounting</u>

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 jeopardize 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

5. Asheim, G.B. 2000: Green National Accounting: why and how? In Environment and Development Economics, Vol. 5 Parts 1 & 2.

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, structured relationships between the environment and the economy, it is hard to know not only what are the various economic causes of environmental damage, 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 SNA (1993) for the first time explicitly included natural resources in its balance sheets 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 sheets provided that institutional units (households, government units, corporations and non-profit organizations) exercise effective ownership over these assets and draw economic benefits from them[6].

National Resource Accounts are currently constructed by a number of industrialized countries, including Norway, Sweden, the Netherlands, Japan, Germany, France, Italy and the UK. Some developing countries are institutionalizing 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.

1.4.3 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

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[6] United Nations, 1999, Integrated Environmental and Economic Accounting, Operational Manual.

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[7]:

- 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 optimization of water allocation to various economic sectors and subsectors.
- 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 prioritized? What are the economic tradeoffs among competing water users?
- What changes in policy and technology can help the country achieve development objectives, given its scarce water resources?

1.4.4 <u>The Present Project in the Context of Natural Resource Accounting</u>

Natural resource accounting is increasingly being viewed worldwide as an important complement to the more traditional systems of national economic accounting. South Africa too is attempting to compile natural resource accounts. More specifically, a national water account is currently being drawn up. This account will consist of an aggregation of catchment accounts, of which the Vaal is obviously one. When complete, the national water accounts will provide a control framework that not only provides a database of all the water used in South Africa, but also relates this water use to such economic aggregates as gross domestic product (value added) and employment. These relationships are also calibrated within the total system. The significance of this for the present study is that the database for the Vaal River system model *de facto* forms part of, and eventually will be fully consistent with, the broader national water accounting system.

1.5 STRUCTURE OF REPORT

This report is structured in the following way:

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7 Lange G & Hassan, Ibid.

Chapter 1: This chapter has dealt with a general background discussion of the project as well as the theory and practice of National Resource Accounts.

Chapter 2: A framework of water resource accounts for analysing the Vaal River system is presented and a general background to the modelling system is given. The supply and the use sides are discussed in detail.

Chapter 3: A historic water balance is derived in this chapter **(objective 1)**.

Chapter 4: This chapter derives demand schedule curves in order to attempt to establish price demand elasticities for the main user categories **(objective 2)**.

Chapter 5: The value of water for each sub-catchment is determined here and is then compared to the supply cost **(objectives 3+4)**.

Chapter 6: This chapter explores various policy and pricing scenarios **(objective 5)**.

Chapter 7: Conclusions and recommendations are presented.

CHAPTER TWO

METHODOLOGY

This chapter does not directly address any study objective as such. However, it paves the way to addressing these objectives by establishing the technical instruments necessary to do so. The first component of this chapter is the discussion of a framework of water resource accounts for the Vaal River system. The second component is the discussion of the mathematical modelling system that was used to simulate a water market for the Vaal River system.

2.1 FRAMEWORK OF WATER RESOURCE ACCOUNTS FOR THE VAAL RIVER SYSTEM

In this section the most important aspects of the water resource accounts that this study compiled for the Vaal River system are discussed.

2.1.1 Type of Accounts

Water resource accounts consist of water stock accounts and water flow accounts i.e. supply and use. In this study only the flow accounts of the Vaal River were derived explicitly from primary data sources. These flow accounts form a basis from which the state of the stock accounts[1] can be inferred implicitly, and in the next section for purposes of the modelling exercise so-called "dummy dams" will be introduced to the system. The defining of these dams and their purpose in the study will be discussed at a later stage. To some extent the dummy dams can be viewed as partial stock accounts.

2.1.2 Valuation of Water

The basis for the water resource accounts is formed by the physical water use accounts. This study has compiled these physical accounts on an annual basis from 1980 to 1998. From the physical accounts a second set of accounts that reflects the economic contribution of water usage by each economic user group is derived. The economic contribution of water can be measured by means of different macroeconomic criteria, for instance surplus value, job creation, contribution to Gross Domestic Product (GDP) etc. In this study, only one criterion was used, namely surplus value or the so-called economic value of water. In the study only the term economic value of water will be used.

The analysis also focuses on the cost of providing raw water to the relevant sectors, as well as the water tariffs and the implicit subsidies to these sectors.

A distinction should be made between the terms "price" and "tariff". The "price" of a good is determined in a market where the quality supplied of a good, is equal to the quantity demanded. However, sometimes services which are completely exhaustible and must be replenished by new stock as consumption continues, are supplied by the government in a direct exchange relationship (e.g. the supply of water). The "prices" which have to be paid for such services, are known as consumer tariffs[2]. It should be noted that throughout this report tariff was used as a proxy for price. The tariff charged per unit consumption, which is collected directly from the consumers, must be sufficient to pay for the full cost of supplying such a service.

Raw water is defined as water in the dam or in the river, before it is purified or bulk distributed. This concept is the most appropriate measure to use when evaluating the efficiency of water use between different use categories and deciding on re-allocation of water. The cost to purify and to distribute it, when

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1) The compilation of the stock accounts could be viewed as a natural extension of this study at a later stage.

2) The differences between the terms price and tariffs is discussed in: Gildenhuys, J.S.H., 1999, Public Financial Management, J.L. van Schaik.

necessary, is for the account of the specific user. In order to determine the cost of water for a specific water use, it is necessary to start at the retail tariff of water and subtract reticulation, storage, bulk and purification costs.

Although raw water is the most appropriate measure with which to evaluate the efficiency of water use, there is a problem associated with it in the case of the Vaal River, namely that water used in agriculture in the Middle Vaal is of a very low quality. This is due to return flows which enter the system below the barrage.

It should be noted that for modelling purposes it has been assumed that raw water quality is homogenous. Different qualities of water, however, would have resulted in different values of water.

2.1.3 Study Area

For development planning purposes, the Vaal River system is normally defined by the various stakeholders from a water use point of view. This differs from the normal practice where planning takes place strictly within the boundaries of catchments. For purposes of this study the study area was defined from a user management perspective. The study area was further subdivided into an Upper Vaal user area and a Lower Vaal user area. Although the names of these two user areas are the same as for the water management areas as defined by DWAF, they do not coincide geographically as explained hereafter. The study area, as defined for this study, encloses more or less the whole Vaal River catchment system, namely the Upper, Middle and Lower Vaal system as depicted in Map 1 (provided at the beginning of this report). It deviates, however, in the sense that a portion of the Lower Vaal catchment is excluded, whilst the Crocodile catchment was added to the Upper catchment. The reason for the latter is the inter-linkage of the Tshwane Metropole to the rest of the industrial metropolis of Gauteng. Although Tshwane is actually in the Crocodile catchment, water is mainly transferred from the Vaal system to it.

The magisterial districts included in this study area are shown in Map 2 and listed in Table 2.1.

MAP 2: MAGISTERIAL DISTRICTS INCLUDED IN THE STUDY AREA.

TABLE 2.1: MAGISTERIAL DISTRICTS INCLUDED IN THE STUDY AREA

UPPER USER REGION	*MIDDLE USER REGION*
Alberton	Barkley West
Amersfoort	Bloemhof
Balfour	Boshof
Benoni	Bothaville
Bethal	Bultfontein
Bethlehem	Christiana
Boksburg	Coligny
Brakpan	Delaryville
Brits	Exelsior
Bronkhorstspruit	Hartswater
Cullinan	Hennenman
Delmas	Herbert
Ermelo	Hoopstad
Frankfort	Kimberley
Germiston	Klerksdorp
Harrismith	Koppies
Heidelberg	Kroonstad
Heilbron	Lichtenburg
Highveld Ridge	Lindley
Johannesburg	Marquard
Karen Park	Odendaalsrus
Krugersdorp	Parys
Middelburg	Potchefstroom
Nigel	Schweizer-Reneke
Oberholzer	Senekal
Pretoria (Tshwane)	Theunnissen
Randburg	Ventersburg
Randfontein	Ventersdorp
Reitz	Viljoenskroon
Roodepoort	Virginia
Rustenburg	Vredefort
Sasolburg	Vryburg
Springs	Warrenton
Standerton	Welkom
Vanderbiljlpark	Wesselsbron
Vereeniging	Winburg
Volksrust	Wolmaransstad
Vrede	
Westonaria	
Witbank	
Wonderboom	

Due to the significant difference in the type of water use in the study area, the river was divided for purposes of this study into two sections, namely the "Upper Vaal" and the "Middle Vaal". The water use of the Upper Vaal is mainly industrial and domestic whilst that of the Middle Vaal is mainly agricultural.

The Upper Vaal catchment ends at the Vaal Barrage (and includes the abstractions from the Barrage) and corresponds closely with the Upper Vaal catchment as defined by the civil engineers, BKS Inc. who maintain a hydrological model of the Vaal River and who provided the water supply data used in this study. The Upper Vaal as defined for this study, closely corresponds to the Upper Vaal catchment, except for the inclusion of the Crocodile catchment.

The Middle Vaal catchment includes the area from the Barrage down to the confluence of the Vaal and Orange Rivers. The Middle Vaal study area includes the whole Middle Vaal catchment as well as a portion of the Lower Vaal catchment. An area to the south west of the Lower Vaal catchment, which contains some magisterial districts in the North Western Free State, *inter alia* Bloemfontein, is excluded.

2.1.4 <u>Classification of Water</u>

Table 2.2 below provides a conceptual picture of the breakdown of total water supply in the Vaal River system. Water resource accounts normally differentiate between the following sources of water:

Groundwater	:	Borehole water
Surface water		
Perennial	:	Rivers that flow all year round e.g. the Vaal River
Ephemeral (seasonal)	:	Rivers that only flow after heavy rains.

However, because of data constraints, for purposes of this study the total water supply is aggregated and the water accounts below do not differentiate between the various water sources for either supply or usage. The result of this is that all water used in the Vaal River system is assumed to come from the Vaal River itself – which is probably not very far from the truth.

2.1.4.1 Supply Classification

The supply classification is reflected in Table 2.2 below:

TABLE 2.2: WATER SUPPLY CLASSIFICATION

Instream		
	-	Net annual run off
Plus	-	Afforestation**
Plus	-	Small Dams
Equals	ANNUAL RUN OFF	
Plus	-	Ecology*
Plus	-	Spillage (Vaal Dam)
Equals	GROSS CATCHMENT YIELD	
Minus	-	Evaporation (Dams)
Minus	-	Spillages
Minus	-	Ecology
Equals	NET CATCHMENT YIELD	
Plus		TRANSFERS IN
	From	Sterkfontein
	From	Lesotho Highlands
	From	Komati
	From	Usuthu
	From	Buffels (Zaaihoek)
Plus		RETURN FLOWS
Equals		SURFACE WATER SUPPLY
Plus		GROUNDWATER SUPPLY
	From	Municipal (boreholes)**
	From	Irrigation (boreholes)**
Equals		TOTAL SUPPLY

* only applicable for Middle Vaal

** contra entries

Total supply is determined as the sum of surface water supply and groundwater supply. Surface water supply is arrived at when the effects of transfers in and return flows have been incorporated in net catchment yield. Net catchment yield, in turn, is obtained when the effects of evaporation and spillage have been removed.

For purposes of WRA it is necessary to disaggregate the gross catchment yield into net annual runoff as measured instream, afforestation and small dams. Afforestation is also a contra entry from the use side, because the water it uses never enters the Vaal River system but is potentially a source of supply. Annual run-off plus the ecological reserve and spillage results in the catchment yield.

Under the supply of groundwater, provision is made for municipal boreholes, as well as for irrigation boreholes. Values for these items are determined as contra entries from the use section in the water balance tables.

2.1.4.2 Water Users

- **Surface Water**

  Water use sectors are categorised and subdivided into the detailed levels reflected in Table 2.3. The main water use sectors are:

  - Municipal use
  - Irrigation use
  - Afforestation use
  - Electricity use, and
  - Heavy Industry use.

  Sub-use sectors are shown in Table 2.3.

TABLE 2.3: WATER USE CLASSIFICATION

1.	MUNICIPAL USE	* Households (Domestic)	• *High Income* - Indoor - Outdoor • *Low Income* - Indoor - Outdoor

		* Light Industry	
		* Parks	
2.	IRRIGATION USE	* Controlled Irrigation * Uncontrolled Irrigation	
3.	AFFORESTATION **		
4.	ELECTRICITY USE		
5.	HEAVY INDUSTRY USE		
6.	ECOLOGY		
7.	TRANSFERS OUT – OLIFANTS		
8 = sum 1-7	TOTAL USE: SURFACE WATER		
9.	TOTAL USE: GROUNDWATER	* Municipal (boreholes) ** * Irrigation (boreholes) **	
8+9	TOTAL USE		

** contra entries

- **Municipal Use**:

  Three main sub-categories are distinguished in this sector:

  - Households (domestic)
  - Upper-Middle Income level above Minimum Wage Level[11]

[11] The Upper-Middle Income category includes categories equal to and above R26 900 (1998 prices) per annum and the Lower Income category incomes below R26 900. These figures were

  - Lower Income level below Minimum Wage Level
- Light Industry using municipal supply
- Municipal Parks

The household groups are further refined to reflect indoor (cooking, cleaning) and outdoor (gardening) use. Water from the Vaal River system as described in Map 1 that is transferred into the Crocodile River catchment in order to augment Tshwane municipal supply, is included in this category.

- **Irrigation Use:**

This category is further subdivided into DWAF controlled and uncontrolled irrigation. The Vaalharts Irrigation Scheme is included in the Middle Vaal section.

- **Afforestation, Electricity and Heavy Industry:**

Afforestation represents commercial plantations and the relevant water reduction effect is taken into account.

The electricity category reflects the water use by Eskom thermal power stations in the study area.

The heavy industry sector is made up by major water users outside municipal areas and includes SASOL in Sasolburg and Secunda, Iscor at Vanderbijlpark and some mining.

- **Groundwater**

In this water use category, a distinction is made between Municipal and Irrigation boreholes.

2.1.5 Time Period

The historical period under consideration is from 1980 to 1998. For each year a set of water resource accounts (water balance tables) was generated. This has been done to analyse trends in the supply and use of water over time. For modelling purposes projections were subsequently made to the year 2015, as discussed in Chapter 6.

2.2 A SYSTEM DYNAMICS MODEL FOR THE VAAL RIVER SYSTEM

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calculated by making use of the Social Accounting Matrix of Conningarth Economists in an internal document

2.2.1 Background

It is assumed that the reader of this document is familiar with the literature on water markets, and an extensive discussion of the theoretical background to the present study will not be provided here. Suffice it to say that the study is broadly in accordance with the seminal work of Gibbons[2)].

For purposes of this study, it was necessary to select an overall modelling framework within which to capture water supply and use data. The static equilibrium models encountered in microeconomics textbooks were considered inadequate for this purpose. Such models can indicate what the end result of supply/use interrelationships will be: what the tariff of water will be in a given catchment, and what the total quantity of water use will be at that tariff. However, such a model does not trace out the path of convergence to that end situation; nor does it provide a very useful vehicle for modelling policy interventions to achieve technical, social or political objectives. It ignores the complexities which a positive water tariff could create for water managers, for example by reducing total demand in part of a catchment and with it also return flows, and cannot deal easily with water of different qualities. Any economic management of water must, moreover, take place within a hydrological system and it is therefore necessary to investigate their mutual interaction.

The aforementioned considerations require the basic microeconomic model to be placed within a more complex modelling framework. This must allow for hydrological relationships to be captured, dynamic paths to equilibrium to be traced and disaggregation to be undertaken to a level where the effect of water pricing on particular social groups or geographic areas can be ascertained. All of this requires an appropriate model that can record and keep track of a myriad of interrelationships and feedback loops. Hence the decision at the start of this study that it would make use of a systems dynamics modelling approach. The majority of variables in a system dynamics model are endogenous within the feedback relationships; relatively few are exogenous. Other characteristics of such a model are time lags and non-linear relationships, which can combine to produce a wide variety of complex relationships.

Systems thinking tries to understand the relationship between processes as they interact with one another. The interaction processes take place over a period of

2) Gibbons, D.C., 1986, 'The Economic Value of Water', *A Study from Resources for the Future, Washington DC. The Johns Hopkins University Press.*

time. Mathematicians understand the processes involved by expressing them as a series of differential equations with respect to time.

A system dynamics computer model analysis tool, STELLA[5], was used to model a variety of complex systems by attempting to understand the underlying relationships between the different parts of the entire system.

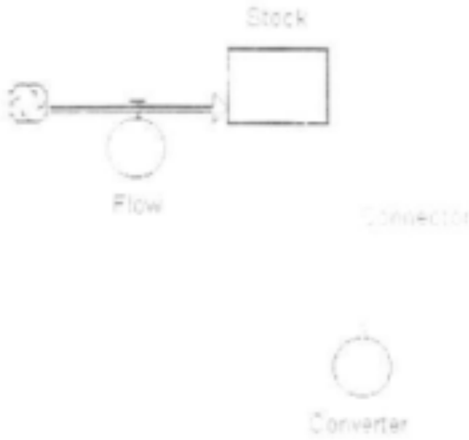
STELLA uses a small number of components in combination to represent quite complex systems. These are: -

1. A Stock
2. A Flow
3. A Converter
4. A Connector.

Diagrammatically, they are represented in Figure 2.1:

5) STELLA is a software package for developing a System Dynamics Computer Model.

FIGURE 2.1



The 'Stock' can represent any accumulation, such as 'Dam contents' or 'Population'. The level or quantity of the stock increases or diminishes according to the amount of deposits and withdrawals made on the stock.

The 'Flow' resembles a pipe with a fluffy cloud at one end. The cloud represents an infinite supply of, for example, 'Water' or 'People'. The actual numbers flowing are regulated by the spigot – the circular object attached to the flow. Just like a domestic water tap, it can be used to regulate the flow into a stock.

The 'Connector' establishes that there is a mathematical relationship between the objects connected together.

Finally, the 'Converter' modifies the relationship between objects by providing a placeholder for equations and short sequences of computer programs.

Objects such as 'Conveyors' (Stocks with a 'time-lag'), as well as arrays of all the above objects supplement these fundamental objects.

Input to the various objects may be in graphical form, or as equations. Output can be as graphs or tables. The tables may be linked to applications such as Microsoft 'Excel' from which high quality graphs can be produced.

An example of a STELLA application is provided in Annexure 2.1.

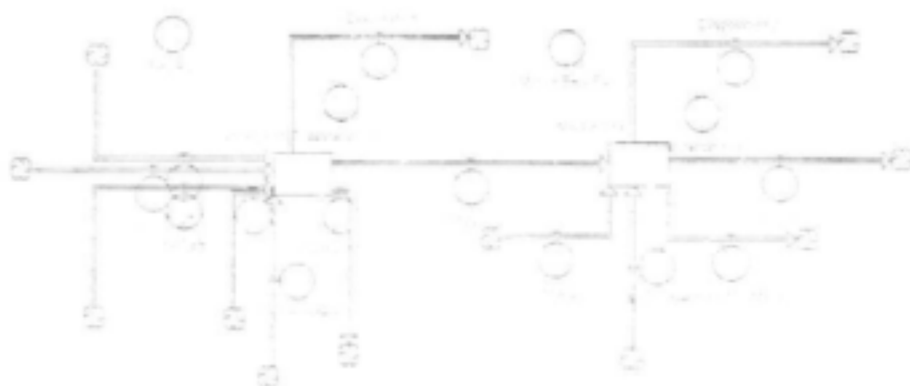
2.2.2 Model for the Vaal System

For the purpose of this study, the total system has been consolidated into two dummy dams represented as the Upper and Middle Vaal systems. In practice these dummy dams represent the Vaal and Bloemhof dams.

Figure 2.2 shows a simplified version of the physical system under consideration.

FIGURE 2.2

Diagram of the Water Balance Model Used in the Simulation



In the above diagram, the rectangular boxes (stocks of water) are simply the reservoirs – Vaal and Bloemhof dams.

The historical flows for the 74 years 1920 to 1994 at monthly intervals have been used as data. They are consolidated flows to the hypothetical dummy dams derived from the physical system model.

2.2.2.1 Supply Model

The water supply classification was already reflected in Table 2.2 and is not repeated here.

An important aspect which should be noted for the model of the Vaal system is that the supply of water is totally insensitive to tariff changes. This is probably true for the period under consideration (until 2015) because the infrastructure and contracts are in place. Over the long-term this would probably not be the case.

For scenario purposes three future levels of net annual run off were developed, namely for Wet, Normal and Dry cycles. These cycle values were obtained by fitting trend lines to the historical flow data for the 74 years 1920 – 1994 at monthly intervals and projecting them into the future. In the case of the "normal" cycle a trend line was fitted to all observed historical values. The "wet" cycle was obtained by fitting a trend to all the peak values of the historical values. The "dry" cycle, in turn, was obtained by fitting a trend line to all the trough values.

A second important element, namely evaporation, is inherent to the system and was generated as a portion of the water balance (i.e. the levels of the two dummy dams in the system on an annual basis).

Transfers in were incorporated as far as possible on the basis of current knowledge.

Return flows were also generated by the model as a constant proportion of use.

2.2.2.2 Use Model

The use categories are shown in Table 2.3 and are not repeated here.

As indicated before, a distinction was made between the Upper and Middle Vaal user areas. All water use categories are included for the Upper Vaal, whilst electricity use and heavy industry use are not applicable for the Middle Vaal area.

Each use category is described by a mathematical equation in the mathematical model of the Vaal River system which is set out in Table 2.4 and discussed further below. It should be noted that the coefficients used in these equations are based on the 1998 total gross use (volume) figures for the Vaal River system. It was assumed that these coefficients would hold for the forecasting period as well.

In each equation the variable on the left hand side (use category) is the dependent variable of the equation. The variables included on the right hand side are exogenous variables or independent variables.

TOTAL GROSS USE (VOLUME) FOR WATER IN THE VAAL RIVER SUPPLY SYSTEM
MILLION M³ PER ANNUM – MATHEMATICAL MODEL

TOTAL USE – UPPER VAAL	[illegible]
A. MUNICIPAL USE	[illegible]
1. Household	[illegible]
High Income	[illegible]
Low Income	[illegible]
2. Industry	[illegible]
3. Parks	[illegible]
B. IRRIGATION USE	[illegible]
C. ELECTRICITY USE	[illegible]
D. HEAVY INDUSTRY USE	[illegible]
TOTAL USE – MIDDLE VAAL	[illegible]
A. MUNICIPAL USE	[illegible]
1. Household	[illegible]
High Income	[illegible]
Low Income	[illegible]
2. Industry	[illegible]
3. Parks	[illegible]
B. IRRIGATION USE	[illegible]
TOTAL USE – VAAL	[illegible]
A. MUNICIPAL USE	[illegible]
1. Household	[illegible]
High Income	[illegible]
Low Income	[illegible]
2. Industry	[illegible]
3. Parks	[illegible]
B. IRRIGATION USE	[illegible]
C. ELECTRICITY USE	[illegible]
D. HEAVY INDUSTRY USE	[illegible]

TABLE 2.4: TOTAL GROSS USE OF WATER IN THE VAAL RIVER SYSTEM

TABLE 2.4 (CONTINUED)

KEY				
DTV	= TOTAL USE : UPPER VAAL		DIV	= TOTAL USE : IRRIGATION
DMTV	= TOTAL MUNICIPAL USE			
			DHIV	= TOTAL USE : HEAVY INDUSTRY
DMHV	= *Municipal Households : Total Use*			
			(CP)%V	= Percentage Change per Category
	DHHIV	= Households : High Income Group		
	DHHcV	= Households : High Income : Indoor Use	GGPV	= Gross Geographic Product per Category
	DHHncV	= Households : High Income : Outdoor Use		
	DHLIV	= Households : Low Income		
	DHLcV	= Households : High Income : Indoor Use	AFFV	= Afforestation
			DOV	= Other (Wetlands)
DMGIV	= *Municipal Use : Parks*		GRWV	= Ground Water
DTB	= TOTAL USE : MIDDLE VAAL			
DMTB	= TOTAL MUNICIPAL USE		DEB	= TOTAL USE : ELECTRICITY
	DHHIB	= Households : High Income Group	(CP)%B	= Percentage Change per Category
	DHHcB	= Households : High Income : Indoor Use		
	DHHncB	= Households : High Income : Outdoor Use	GGPB	= Gross Geographic Product per Category
	DHLIB	= Households : Low Income	HECTB	= Hectares under irrigation
	DHLcB	= Households : High Income : Indoor Use		
	DHLncB	= Households : High Income : Outdoor Use	AFFB	= Afforestation
			DOB	= Other (Wetlands)
DMLIB	= *Municipal Use : Light Industry*			
DMGIB	= *Municipal Use : Parks*		GRWVB	= Ground Water
DMT	= TOTAL MUNICIPAL USE		DE	= TOTAL USE : ELECTRICITY
DMH	= *Municipal Households : Total use*		DHI	= TOTAL USE : HEAVY INDUSTRY
	DHHI	= Households : High Income Group	(CP)%	= Percentage Change per Category
	DHHnc	= Households : High Income : Outdoor Use	GGP	= Gross Geographic Product per Category
	DHLI	= Households : Low Income	HECT	= Hectares under irrigation
	DHLc	= Households : High Income : Indoor Use		
			DO	= Other (Wetlands)
DMLI	= *Municipal Use: Light Industry*			

The equation describing each user category can be explained as follows:

Total water use per category = **[average water use per unit + change in water use due to a tariff change] x total no of units**

- Mathematically, this can be expressed as follows:

  $D = [a + b(\Delta T)] \times C$

  Where

D	=	Total use for a category
a	=	Average use per user unit
b	=	Change in unit use due to a given tariff change
ΔT	=	Change in water tariff
C	=	Total number of user units (driver/exogenous variable)

- For example in Table 2.4 the fifth mathematical equation:
  Municipal use: Households: High Income: Indoor,

  DHHcV = [40.7284 – 10.5894 (CP)%1V] POP1V

  can be interpreted as follows (for key to variables see Table 2.4 (cont.)):

Average use per capita	= 40.7284 m^3/annum
Change in water units used due to a given tariff change	= 10.5894 m^3/annum
Percentage tariff change	= CP%1V

  Total number of persons = POP1V (Driver/exogenous variable = Population size in this category).

- **Average use term**

  The **average use** i.e. a in the equation above, expresses a unit use of water, which could be per capita, per Gross Geographic Product (GGP) or per Hectare depending on the equation that is described. The average terms represent the constant portions of these equations. Calculation of unit terms was based on use data for 1998 which were supplied by BKS and DWAF (Annexure 2.2, Table A.2.2.2).

- **Change in use term**

  - Since the focus here is on tariff as a determining factor, the variable part (change in use or b) of the **use per unit** equation was obtained by adapting (modifying) the definition of price elasticity (A detailed discussion is given in Annexure 2.2, Table A.2.2.3.). The change in use term consists of two components namely an elasticity and a demand component. These components enter the equation multiplicatively.

The unit use portion was calculated as indicated above, whilst the elasticity portion was derived from underlying demand schedules. The estimation of these schedules is discussed in Chapter 4. The calculation of these terms for Municipal use (Upper Vaal) is given in Annexure 2.2, Table A.2.2.2.

In order to convert these unit use functions to total use, these functions were multiplied with their respective "drivers", namely population, GGP or hectares.

A detailed discussion of the individual use equations as well as the exogenous variables involved in the model, is included in Annexure 2.2.

These "drivers" enter these mathematical equations as exogenous variables. That is, they have an effect on the value of the dependent variable (user category) but are not in turn, affected by the dependent variable.

There are four main exogenous variables in the model, namely:

- *Percentage Tariff Change* (where tariff serves as a proxy for price);
- *Population*;
- *Gross Geographic Product*; and
- *Irrigated Hectares*.

Please note that the last three exogenous variables also served as "drivers" in their respective mathematical equations. That is, they have been used to express their respective mathematical equations in unit terms. For instance in the case of agriculture use, the equation is expressed in terms of the volume of water used per hectare (m^3 per hectare per annum). For household use it was expressed in per capita terms (See Annexure 2.1 Table A.2.2.3) and Industry per R million GGP per annum. In order to convert these unit functions to total use functions, they have to be multiplied by these drivers (exogenous variables).

2.2.2.3 Calibration Procedure

If the model is working correctly, there should be good correlation between the observed stock of water in the dummy dams of the model and the observed levels of the Vaal and Bloemhof dams. As can be seen from Figures 2.3 and 2.4, this is the case.

FIGURE 2.3

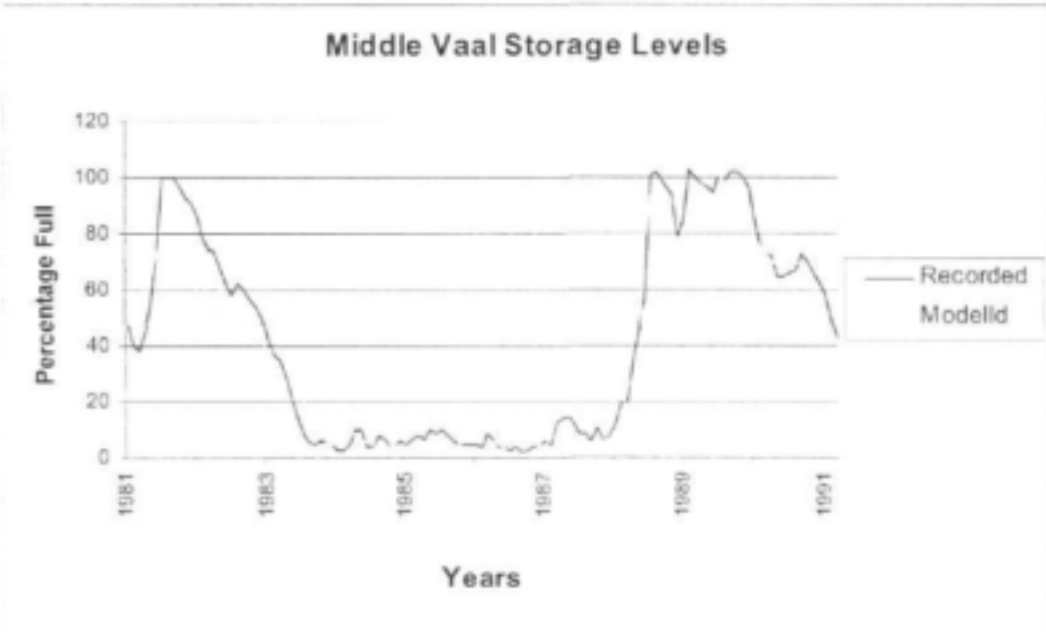
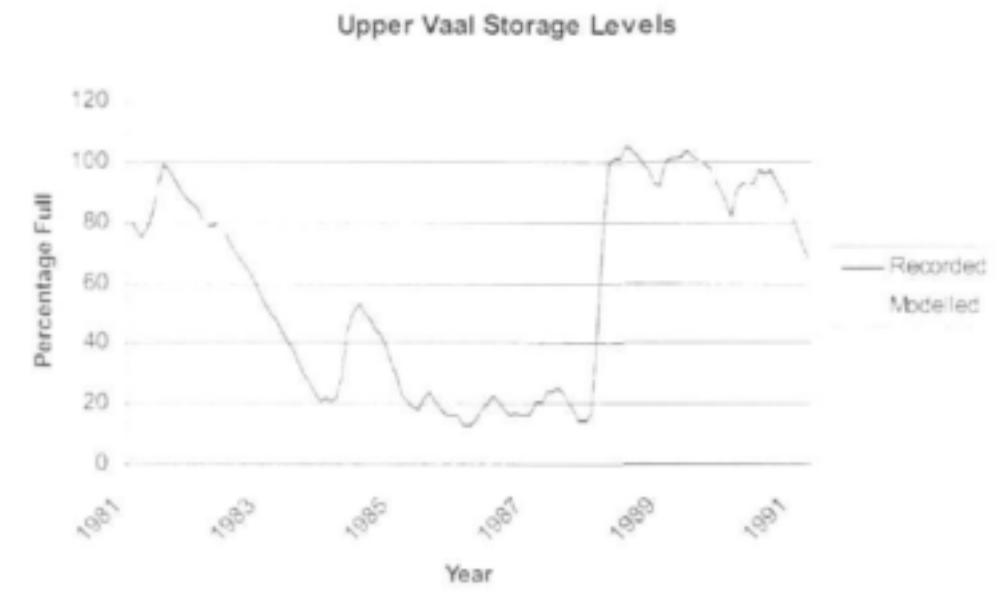


FIGURE 2.4


Upper Vaal Storage Levels
120
100
80
60
40
20
0
Percentage Full
1981
1983
1985
1987
1989
1991
Year
Recorded
Modelled

CHAPTER THREE

HISTORICAL WATER BALANCE (PHYSICAL UNITS)

The first objective of this research initiative was to derive a water balance. In order to achieve this a historical water balance in physical units for the Vaal River system is developed in this chapter. This is based on a formal structure of water resource accounts in physical units.

There are two main sections in this chapter. The first deals with data sources and methods and the second with a discussion of a framework for Water Resource Accounting (WRA).

3.1 DATA SOURCES AND METHODS

In this section the data sources, and in some instances the methodology used to calculate the relevant information, are described.

3.1.1 Water Supply

The reader is referred to Table 2.2 for the classification of water supply. The supply data sources are arranged for two areas namely the Upper Vaal and Middle Vaal.

All inflows (including projected inflows from 2000 to 2015) were computed by BKS. Interpolations were made to cover small gaps in historical data. In the case of inflow data, the flows were simply applied in the graphical form presented.

Augmentation data for the Sterkfontein and Katse dams was also provided by BKS.

Because actual evaporation data was not available and because the evaporation losses represent a minor (albeit significant) portion of the water balance, the simulation model was used to estimate the evaporation. The data and method were supplied by BKS.

3.1.2 Water Use

3.1.2.1 Introduction

The various water use sectors identified in the Vaal River system were listed in Table 2.3.

In terms of the mathematical model these water use sectors represent the endogenous or dependent variables.

3.1.2.2 Endogenous Data

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

In order to obtain the most complete detailed data set possible, unpublished data obtained from BKS and DWAF were combined. Historically, this data set ranges from 1980 to 1998. The unit of measurement in all cases was million m^3 per annum. For modelling purposes, 1998 was considered to be the base year.

Projections for water use up to 2015 were also obtained from DWAF. This data was used to compare projections done by the mathematical use model.

Specific sources and methods pertaining to each individual use sector will now be discussed in detail.

A: MUNICIPAL USE

Only a total municipal use figure was available from the above-mentioned sources. In order to present a more detailed user profile, assumptions had to be made and certain percentages had to be applied to this total. See Annexure 2.2, Table A.2.2.2 in this regard.

In order to reflect the usages of Households (i.e. domestic users), Light Industries and Parks, percentages from information published in Vaal

Augmentation Study, October 1995, p (1)[1], and p 9-2 were applied. These percentages are as follows:

Households	40 %
Light Industries	38 %
Parks	22 %
Total municipal use	100 %

Households

A sub-division of household use between high income and low income users was calculated by using percentages obtained from Vaal Augmentation Study[2], October 1995, p 9.4. This source also indicates that the Rand Water Board sells approximately 25 % of its water to predominantly lower income areas. From this it was deduced that the remainder, 75 %, goes to higher income areas. Also see Annexure 2.2, Table A.2.2.2.

B: **IRRIGATION USE**

Total irrigation use was obtained from DWAF. The split between controlled and uncontrolled irrigation could be calculated from data supplied by BKS.

C: **AFFORESTATION**

The Afforestation use component was isolated from Irrigation use, by using unpublished data from BKS.

D: **ELECTRICITY USE**

This component was available from DWAF.

E: **HEAVY INDUSTRY USE**

1) Department of Water Affairs and Forestry, October 1995, Vaal Augmentation Study: Water Demand in the VRSSA.

2) Department of Water Affairs and Forestry, October 1995, ibid.

Historical figures were also available from DWAF.

3.1.2.3 Exogenous Data

Exogenous (or independent) variables are those variables which affect or determine the values of the endogenous (or dependent variables) in the model. There are four main exogenous variables in the model, namely:

- Tariff percentage change (where tariff serves as a proxy for price);
- Population;
- Gross Geographic Product; and
- Irrigated Hectares.

Most of these variables required quite extensive calculations and various assumptions. This is discussed in detail in Annexure 3.1.

The last three exogenous variables were also used as "drivers" in their respective mathematical equations in the model.

3.2 WATER BALANCE IN PHYSICAL UNITS

The main objective of this section is to develop an accounting structure for water resource accounts in physical units. This structure is made up of the following components:

- The water balance in the Vaal River.
- Composition of water supply in the Upper, Middle and Total Vaal River.
- Composition of water use for the Upper, Middle and Total Vaal River.
- Over- or under-utilization of water in the Vaal River.

The water resource accounts in physical units form the nucleus of the calculations. All other calculations are based on the water supply and use figures in physical units.

3.2.1 Water Balance

Table 3.1 reflects the water balance in the Vaal River for 1998.

TABLE 3.1

WATER BALANCE IN THE VAAL RIVER SYSTEM FOR 1998 (MILLION m³)

SUPPLY (Million m3)		UPPER VAAL	MIDDLE VAAL
	- Net annual run off (in system)	1,499.64	230.63
	- Afforestation**	26.82	-
	- Small Dams	166.50	224.86
	- 1. ANNUAL RUN OFF	1,692.96	455.49
PLUS	- Ecology	NA	51.23
	- Spillage (Vaal Dam)	NA	50.04
CATCHMENT YIELD		1,692.96	556.76
MINUS	- Evaporation (Dams)	339.96	297.94
	- Spillage	50.04	59.04
	- Ecology	51.23	51.23
NET CATCHMENT SUPPLY		1,251.73	148.55
PLUS	2. TRANSFERS IN	762.00	-
	- Sterkfontein	550.00	-
	- Lesotho Highlands	-	-
	- Komati	81.00	-
	- Usutu	81.00	-
	- Buffalo (Zaaihoek)	50.00	-
PLUS	3. RETURN FLOWS	512.90	109.65
GROSS SUPPLY : SURFACE WATER		2,526.53	258.20
TOTAL SUPPLY GROUNDWATER		80.24	-
-	Municipal (boreholes)**	80.24	-
-	Irrigation (boreholes)**	-	-
TOTAL SUPPLY		**2,606.77**	**258.20**

GROSS USE (Million m3)		UPPER		Excess / (Deficit) MIDDLE	UPPER
	VAAL	VAAL	VAAL	VAAL	
1. MUNICIPAL USE		1,138.92	195.66		
1.1. Households	454.77	78.26			
1.1.1 High Income		341.08	58.70		
- Consumptive		136.43	23.48		
- Non-Consumptive		204.65	35.22		
1.1.2 Low Income	113.69	19.57			
- Consumptive		108.31	18.58		
- Non-Consumptive		5.88	3.99		
1.2. Light Industry		432.05	74.35		
1.3. Parks		251.12	43.05		
2. IRRIGATION USE		207.87	806.11		
- Controlled Irrigation		89.48	649.81		
- Uncontrolled Irrigation		118.39	195.11		
3. AFFORESTATION**		26.82	-		
4. ELECTRICITY USE		263.09	-		
5. HEAVY INDUSTRY USE		131.61	-		
6. TRANSFERS OUT (OLIFANTS)	150.00				
TOTAL USE SURFACE WATER			1,916.71	1,001.77	
TOTAL USE GROUNDWATER			80.24	-	
- Municipal (boreholes)**			80.24	-	
- Irrigation (boreholes)**			-	-	
TOTAL USE		1,996.55	1,001.77	**610.22**	-743

** contra entries.

From this table it can be noted that the Upper Vaal exhibits a surplus of 610 Mm^3 whereas a deficit of 743 Mm^3 existed in the Middle Vaal. This implies that in the Upper Vaal more water is supplied than is used. This is balanced by transfers from the Upper to the Middle Vaal.

It is also important to take note of changes in water utilization levels over time for the Upper Vaal, Middle Vaal and Total Vaal River systems.

- Table 3.2 shows the utilization level of water for the Upper Vaal River system.
- Table 3.3 shows the utilization level of water for the Middle Vaal River system.
- Table 3.4 shows the utilization of water within the Total Vaal River system.

It is difficult to arrive at conclusions regarding the utilization of water over time if the real annual supply and use figures are compared separately, because the supply of water (i.e. rainfall) is very erratic on a year to year basis. Accordingly, in order to identify the trend in the availability of water in the Vaal River system, the following steps were followed.

Step 1: Standardise net annual runoff.

Due to erratic rainfall figures it was necessary to make use of an average annual runoff. This was done by calculating an average annual runoff for the period 1989 to 1998.

Step 2: Adjust supply for transfers in.

In order to arrive at an appropriate comparison between supply and demand the annual runoff over the historical period was adjusted by a sustainable transfer-in figure.

Step 3: Determine water availability.

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 columns of Tables 3.2, 3.3 and 3.4 for the Upper, Middle and Total Vaal River systems respectively.

TABLE 3.2

TOTAL WATER BALANCE : UPPER VAAL SYSTEM

[physical units - million m3]

Years	Total supply	Average supply	Total water use	Surplus/ deficit	Total water use/ Average supply [percentage]
1980	1,588	2,533	1,362	226	53.8%
1981	2,075	2,533	1,485	590	58.6%
1982	973	2,533	1,628	-655	64.3%
1983	1,080	2,533	1,467	-387	57.9%
1984	2,254	2,533	1,422	832	56.1%
1985	1,639	2,533	1,440	199	56.8%
1986	1,946	2,533	1,452	494	57.3%
1987	2,146	2,533	1,475	671	58.2%
1988	4,437	2,533	1,540	2,896	60.8%
1989	2,216	2,533	1,609	607	63.5%
1990	1,940	2,533	1,663	276	65.7%
1991	1,896	2,533	1,764	132	69.6%
1992	978	2,533	1,865	-887	73.6%
1993	2,459	2,533	1,776	683	70.1%
1994	2,890	2,533	1,865	1,025	73.6%
1995	2,089	2,533	1,735	354	68.5%
1996	5,021	2,533	1,817	3,204	71.7%
1997	1,974	2,533	1,945	29	76.8%
1998	2,607	2,533	1,916	690	75.6%

From Table 3.2 it should be clear that the water utilization level increased from 53,8 % in 1980 to 75,6 % in 1998 for the Upper Vaal River system even though it fluctuated over this period. The same trend of increased utilization applies for the Middle and Total Vaal River systems as shown in Tables 3.3 and 3.4 respectively.

For the Middle Vaal River system the water utilization level increased from 175.8 % in 1980 to 204.3 % in 1998. The increase is due to a usage increase without an equivalent increase in water supply. However in practice, water releases from the Vaal Dam compensate for this deficit.

TABLE 3.3

TOTAL WATER BALANCE : MIDDLE VAAL SYSTEM

[physical units - million m3]

Years	Total supply	Average supply	Total water use	Surplus/ deficit	Total water use/ Average supply [percentage]
1980	-487	564	991	-1,479	175.8%
1981	433	564	992	-559	175.9%
1982	432	564	1,007	-574	178.5%
1983	288	564	951	-663	168.7%
1984	505	564	956	-451	169.5%
1985	360	564	973	-614	172.5%
1986	340	564	985	-645	174.6%
1987	862	564	986	-124	174.9%
1988	671	564	994	-323	176.3%
1989	571	564	1,007	-435	178.5%
1990	550	564	1,041	-491	184.6%
1991	530	564	1,105	-575	196.0%
1992	193	564	1,131	-939	200.5%
1993	678	564	1,134	-455	201.0%
1994	726	564	1,235	-509	219.0%
1995	257	564	1,213	-956	215.2%
1996	1,305	564	1,221	84	216.5%
1997	570	564	1,132	-562	200.7%
1998	558	564	1,152	-594	204.3%

In Table 3.4 it is shown that the water utilization level within the total Vaal River system increased from 71,1 % % in 1980 to 94,2 % in 1998.

TABLE 3.4

WATER BALANCE: TOTAL VAAL SYSTEM

[Physical Units - million m3]

Years	Total supply	Average supply	Total water use	Surplus/ deficit	Total water use/ Average supply [percentage]
1980	1,102	3,097	2,203	-1,101	71.1%
1981	2,508	3,097	2,326	182	75.1%
1982	1,405	3,097	2,485	-1,079	80.2%
1983	1,368	3,097	2,268	-900	73.2%
1984	2,760	3,097	2,227	532	71.9%
1985	1,998	3,097	2,263	-265	73.1%
1986	2,286	3,097	2,288	-2	73.9%
1987	3,008	3,097	2,311	696	74.6%
1988	5,108	3,097	2,385	2,723	77.0%
1989	2,787	3,097	2,466	322	79.6%
1990	2,490	3,097	2,554	-64	82.5%
1991	2,426	3,097	2,719	-293	87.8%
1992	1,171	3,097	2,846	-1,675	91.9%
1993	3,137	3,097	2,760	377	89.1%
1994	3,616	3,097	2,950	666	95.2%
1995	2,346	3,097	2,798	-452	90.4%
1996	6,326	3,097	2,887	3,438	93.2%
1997	2,544	3,097	2,927	-383	94.5%
1998	2,865	3,097	2,918	-53	94.2%

3.2.2 Contribution to the Water Supply

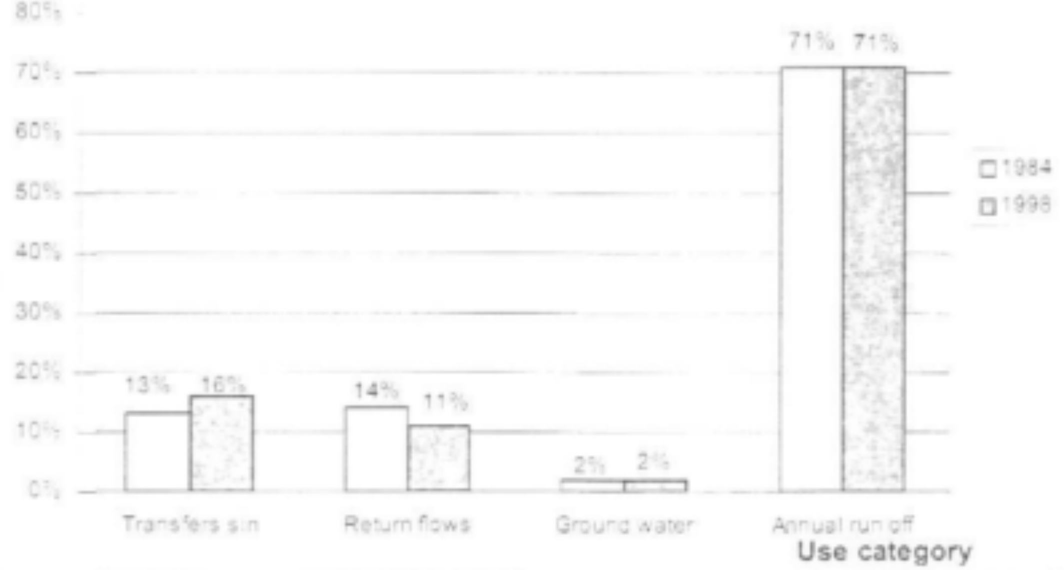
In this section the focus is on the contribution of various sources of water supply in the Upper, Middle and Total Vaal River system.

- Table 3.5 shows the contribution of water supply in the Upper Vaal River system.
- Table 3.6 shows the contribution to water supply in the Middle Vaal River system.
- Table 3.7 shows the contribution to water supply for the total Vaal River system.

These tables provide a detailed supply classification. In view of the erratic rainfall situation discussed before, it was necessary to smooth the annual figures by using a five year moving annual average method. The figures are adjusted for ecology and spillages.

Chart 3.1 gives a breakdown of the contribution of various sources of water supply in the total Vaal River system for 1984 and 1998 respectively. Important to note is that this chart differs from the percentages in Tables 3.5 to 3.7. In these charts ecology and spillages have been excluded.

Chart 3.1 : Contributon to the water supply in the Total Vaal River system

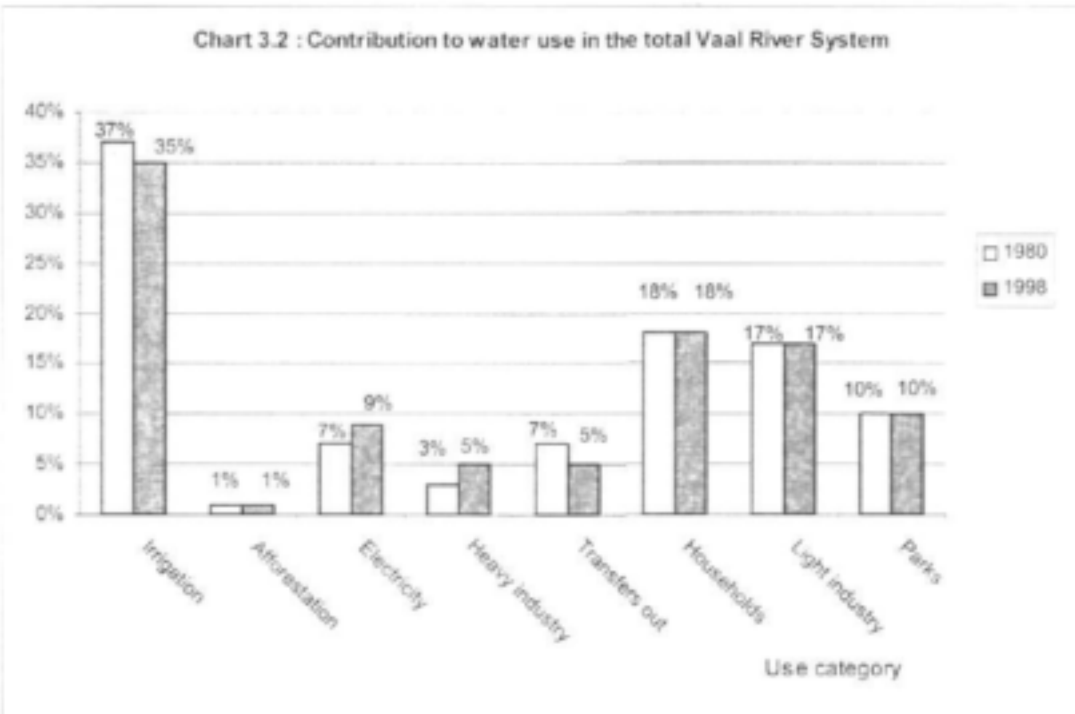


From these chart it is evident that annual run off has remained constant. Transfers in exhibit an increase from 13 % in 1980 to 16 % in 1998. Return flows declined from 14 % in 1980 to 11 % in 1998.

3.2.3 Contribution to Water Use

Tables 3.8, 3.9 and 3.10 show the contribution to sectoral water use for the Upper, Middle and Total Vaal River system respectively for the period 1980 to 1998. From Table 3.10 it is evident that water use for irrigation purposes is a paramount feature. The other main users of water are light industry, electricity and parks. Water use by heavy industry and afforestation represents a relatively small portion of total water use.

Chart 3.2 shows the breakdown of the contribution to sectoral water use for the total Vaal River system for 1980 and 1998 respectively.



From Chart 3.2 it can be observed that irrigation is still the main user of water as its water utilization level stood at 35 % of total water use in 1998. In 1980 this utilization level stood at 37 % of total water use which implies a slight decrease over the period. The other important users are light and heavy industries with 22

% in 1998 whereas in 1980 this figure was 20 %. Another notable trend is that water use for households has remained at 18 % of total use.

TABLE 3.5

Contribution to water supply in the Upper Vaal system (Five year moving average)

(Percentage distribution)

Year	Annual run off	Ecology & spillage	Transfers in	Return flows	Ground water	Total	Total supply [million m3]
1984	92.2%	-44.6%	26.5%	22.4%	3.5%	100%	1,593.9
1985	78.9%	-36.3%	31.4%	22.3%	3.7%	100%	1,604.0
1986	70.0%	-26.7%	30.1%	22.6%	4.0%	100%	1,578.2
1987	70.0%	-22.1%	28.9%	19.7%	3.5%	100%	1,812.8
1988	84.1%	-20.2%	19.1%	14.4%	2.6%	100%	2,484.2
1989	98.8%	-34.7%	18.8%	14.4%	2.6%	100%	2,476.7
1990	102.6%	-34.8%	15.2%	14.3%	2.7%	100%	2,536.8
1991	107.6%	-35.8%	10.8%	14.6%	2.8%	100%	2,527.0
1992	110.0%	-39.8%	10.2%	16.4%	3.3%	100%	2,293.4
1993	92.2%	-42.5%	26.1%	20.1%	4.1%	100%	1,897.8
1994	74.3%	-22.3%	24.6%	19.3%	4.1%	100%	2,032.6
1995	62.6%	-21.0%	35.3%	19.2%	3.9%	100%	2,062.5
1996	75.0%	-24.4%	31.2%	15.2%	3.0%	100%	2,687.3
1997	73.5%	-23.1%	32.1%	14.7%	2.7%	100%	2,886.5
1998	78.5%	-23.2%	26.6%	15.5%	2.7%	100%	2,916.0

TABLE 3.6

Contribution to water supply in the Middle Vaal system (Five year moving average)

(Percentage distribution)

Year	Annual run off	Ecology & spillage	Transfers in	Return flows	Total	Total supply [million m3]
1984	386.0%	-331.0%	0.0%	45.0%	100%	234.5
1985	220.7%	-146.8%	0.0%	26.1%	100%	403.7
1986	172.7%	-100.1%	0.0%	27.4%	100%	385.2
1987	145.7%	-68.1%	0.0%	22.4%	100%	471.1
1988	218.9%	-138.2%	0.0%	19.3%	100%	547.6
1989	275.5%	-194.3%	0.0%	18.8%	100%	560.8
1990	270.5%	-188.2%	0.0%	17.7%	100%	598.9
1991	276.9%	-193.6%	0.0%	16.8%	100%	636.8
1992	324.4%	-245.8%	0.0%	21.4%	100%	502.9
1993	234.9%	-156.3%	0.0%	21.4%	100%	504.4
1994	164.2%	-84.3%	0.0%	20.1%	100%	535.1
1995	163.2%	-85.5%	0.0%	22.3%	100%	476.6
1996	187.3%	-103.9%	0.0%	16.6%	100%	631.8
1997	194.1%	-108.9%	0.0%	14.7%	100%	707.2
1998	206.6%	-123.4%	0.0%	16.8%	100%	623.3

TABLE 3.7

Contribution to water supply in the Total Vaal system (Five year moving average)

(Percentage distribution)

Year	Annual run off	Ecology & spillage	Transfers in	Return flows	Ground water	Total	Total supply [million m3]
1984	129.9%	-81.3%	23.1%	25.3%	3.1%	100%	1,828.4
1985	107.4%	-58.5%	25.1%	23.0%	3.0%	100%	2,007.8
1986	90.2%	-41.1%	24.2%	23.6%	3.2%	100%	1,963.4
1987	85.6%	-31.6%	23.0%	20.3%	2.8%	100%	2,283.9
1988	108.5%	-41.5%	15.7%	15.3%	2.1%	100%	3,031.9
1989	131.4%	-64.2%	15.4%	15.2%	2.2%	100%	3,037.4
1990	134.7%	-64.1%	12.3%	15.0%	2.2%	100%	3,135.8
1991	141.7%	-67.6%	8.6%	15.0%	2.3%	100%	3,163.7
1992	148.5%	-76.9%	8.4%	17.3%	2.7%	100%	2,796.3
1993	122.2%	-66.4%	20.6%	20.3%	3.3%	100%	2,402.2
1994	93.0%	-35.2%	19.5%	19.5%	3.2%	100%	2,567.9
1995	81.5%	-33.1%	28.7%	19.7%	3.2%	100%	2,539.1
1996	96.4%	-39.5%	25.3%	15.4%	2.4%	100%	3,319.1
1997	97.3%	-40.0%	25.8%	14.7%	2.2%	100%	3,593.7
1998	101.0%	-40.8%	21.9%	15.7%	2.2%	100%	3,539.3

TABLE 3.8

Contribution to water use in the Upper Vaal River system (excluding ground water)

(Percentage distribution)

Year	Municipal Use				Irrigation Use	Afforestation	Electricity Use	Heavy industry Use	Transfers out	Total water Use	Total water Use [million m3]
	Households		Light industry	Parks							
	High income	Low income									
1980	17.6%	5.7%	21.5%	12.4%	14.8%	2.0%	11.4%	4.5%	11.6%	100.0%	1561.9
1981	16.3%	5.4%	20.7%	12.0%	13.5%	1.8%	15.5%	4.6%	10.1%	100.0%	1481.6
1982	16.4%	5.5%	20.8%	12.0%	12.3%	1.6%	16.2%	5.9%	9.2%	100.0%	1627.9
1983	15.0%	5.0%	19.0%	11.0%	13.7%	1.8%	17.5%	6.8%	10.2%	100.0%	1466.8
1984	14.2%	4.7%	18.0%	10.4%	14.1%	1.9%	18.7%	7.3%	10.6%	100.0%	1421.6
1985	14.4%	4.8%	18.2%	10.6%	14.0%	1.9%	18.4%	7.4%	10.4%	100.0%	1499.0
1986	14.5%	4.8%	18.4%	10.6%	13.8%	1.8%	18.1%	7.5%	10.3%	100.0%	1452.3
1987	14.7%	4.9%	18.6%	10.8%	13.6%	1.8%	17.8%	7.6%	10.2%	100.0%	1478.2
1988	15.3%	5.1%	19.3%	11.2%	13.0%	1.7%	16.9%	7.6%	9.7%	100.0%	1540.4
1989	15.8%	5.3%	20.1%	11.6%	12.5%	1.7%	16.1%	7.6%	9.3%	100.0%	1609.0
1990	16.2%	5.4%	20.6%	11.9%	12.1%	1.6%	15.5%	7.6%	9.0%	100.0%	1661.3
1991	17.2%	5.2%	21.8%	12.6%	11.5%	1.5%	13.7%	7.4%	8.5%	100.0%	1764.2
1992	17.0%	5.7%	21.5%	12.4%	10.9%	1.4%	15.5%	7.6%	8.0%	100.0%	1864.8
1993	17.3%	5.8%	21.9%	12.7%	11.5%	1.5%	13.0%	7.8%	8.4%	100.0%	1776.1
1994	17.9%	6.0%	22.7%	13.1%	11.0%	1.4%	12.7%	7.1%	8.0%	100.0%	1864.6
1995	17.3%	5.8%	21.9%	12.7%	11.8%	1.5%	12.5%	7.9%	8.6%	100.0%	1735.3
1996	17.6%	5.7%	21.5%	12.5%	11.4%	1.5%	14.4%	7.8%	8.3%	100.0%	1816.7
1997	18.2%	6.1%	23.1%	13.3%	10.6%	1.4%	12.3%	7.3%	7.7%	100.0%	1945.1
1998	17.8%	5.8%	22.5%	13.1%	10.8%	1.4%	13.7%	6.9%	7.8%	100.0%	1916.3

TABLE 3.9

Contribution to water use in the Middle Vaal River system (excluding ground water)

(Percentage distribution)

Year	Municipal Use: Households: High income	Low income	Light industry	Parks	Irrigation Use	Afforestation	Electricity Use	Heavy industry Use	Transfers out	Total water Use	Total water Use [million m3]
1980	6.0%	2.0%	7.6%	4.4%	61.9%	0.0%	0.0%	0.0%	15.1%	100.0%	991.0
1981	6.0%	2.0%	7.6%	4.4%	61.9%	0.0%	0.0%	0.0%	15.1%	100.0%	991.8
1982	6.4%	2.1%	8.6%	4.7%	61.9%	0.0%	0.0%	0.0%	14.9%	100.0%	1,006.6
1983	5.0%	1.7%	6.3%	3.6%	67.6%	0.0%	0.0%	0.0%	15.8%	100.0%	951.2
1984	5.1%	1.7%	6.4%	3.7%	67.3%	0.0%	0.0%	0.0%	15.7%	100.0%	955.6
1985	5.5%	1.8%	7.6%	4.1%	66.1%	0.0%	0.0%	0.0%	15.4%	100.0%	971.4
1986	5.9%	2.0%	7.4%	4.3%	65.3%	0.0%	0.0%	0.0%	15.2%	100.0%	985.7
1987	5.9%	2.0%	7.4%	4.3%	65.2%	0.0%	0.0%	0.0%	15.2%	100.0%	986.1
1988	6.1%	2.0%	7.7%	4.4%	64.7%	0.0%	0.0%	0.0%	15.1%	100.0%	994.1
1989	6.4%	2.1%	8.6%	4.7%	63.9%	0.0%	0.0%	0.0%	14.9%	100.0%	1,006.5
1990	6.4%	2.1%	8.1%	4.7%	64.3%	0.0%	0.0%	0.0%	14.8%	100.0%	1,030.8
1991	6.8%	2.3%	8.6%	5.0%	63.7%	0.0%	0.0%	0.0%	13.6%	100.0%	1,104.9
1992	6.0%	2.0%	7.6%	4.4%	66.7%	0.0%	0.0%	0.0%	13.3%	100.0%	1,131.1
1993	5.8%	1.9%	7.3%	4.2%	67.5%	0.0%	0.0%	0.0%	13.2%	100.0%	1,133.5
1994	5.8%	1.9%	7.4%	4.3%	68.1%	0.0%	0.0%	0.0%	12.1%	100.0%	1,235.0
1995	5.5%	1.8%	6.9%	4.0%	69.1%	0.0%	0.0%	0.0%	12.4%	100.0%	1,213.2
1996	5.4%	1.8%	6.8%	3.9%	69.8%	0.0%	0.0%	0.0%	12.3%	100.0%	1,220.8
1997	5.2%	1.7%	6.6%	3.8%	69.5%	0.0%	0.0%	0.0%	13.3%	100.0%	1,131.6
1998	5.1%	1.7%	6.5%	3.7%	70.0%	0.0%	0.0%	0.0%	13.0%	100.0%	1,151.8

TABLE 3.10

Contribution to water use in the Total Vaal River system (excluding ground water)

(Percentage distribution)

Year	Municipal Use				Irrigation Use	Afforestation	Electricity Use	Heavy industry Use	Transfers out	Total water Use	Total water Use [million m3]
	Households		Light industry	Parks							
	High income	Low income									
1980	13.2%	4.1%	16.7%	9.7%	38.3%	1.3%	7.1%	2.7%	6.8%	100.0%	2,202.9
1981	13.0%	4.3%	16.5%	9.5%	36.3%	1.3%	9.9%	2.9%	6.3%	100.0%	2,336.8
1982	13.3%	4.1%	16.9%	9.8%	34.0%	1.4%	10.6%	3.8%	6.0%	100.0%	2,481.5
1983	11.8%	3.9%	14.9%	8.6%	37.2%	1.2%	11.3%	4.4%	6.6%	100.0%	2,268.0
1984	11.3%	3.8%	14.1%	8.4%	37.9%	1.2%	11.9%	4.6%	6.7%	100.0%	2,327.1
1985	11.5%	4.0%	14.6%	8.5%	37.5%	1.3%	11.7%	4.7%	6.6%	100.0%	2,263.4
1986	11.7%	3.9%	14.9%	8.6%	36.4%	1.3%	11.9%	4.7%	6.6%	100.0%	2,288.0
1987	11.9%	4.0%	15.1%	8.7%	36.5%	1.2%	11.3%	4.9%	6.5%	100.0%	2,311.5
1988	12.1%	4.1%	15.7%	9.1%	35.1%	1.1%	10.9%	4.9%	6.3%	100.0%	2,381.5
1989	12.9%	4.3%	16.1%	9.5%	33.2%	1.1%	10.5%	4.9%	6.1%	100.0%	2,465.6
1990	13.2%	4.1%	16.7%	9.2%	33.1%	1.1%	10.1%	5.0%	5.9%	100.0%	2,551.1
1991	13.9%	4.6%	17.7%	10.2%	31.9%	1.0%	8.9%	4.8%	5.5%	100.0%	2,719.1
1992	13.5%	4.5%	17.8%	9.9%	31.7%	0.9%	10.1%	5.0%	5.3%	100.0%	2,815.9
1993	13.5%	4.5%	17.1%	9.9%	33.1%	1.0%	8.1%	5.0%	5.3%	100.0%	2,794.7
1994	13.8%	4.6%	17.5%	10.3%	33.0%	0.9%	8.0%	4.7%	5.1%	100.0%	2,910.6
1995	13.1%	4.1%	16.6%	9.6%	37.1%	1.0%	7.7%	4.9%	5.1%	100.0%	2,798.5
1996	13.0%	4.3%	16.3%	9.5%	36.7%	0.9%	9.1%	4.9%	5.2%	100.0%	2,887.5
1997	14.1%	4.7%	17.9%	10.3%	33.9%	0.9%	8.1%	4.9%	5.1%	100.0%	2,926.7
1998	13.7%	4.6%	17.4%	10.0%	34.7%	0.9%	9.0%	4.5%	5.1%	100.0%	2,918.1

CHAPTER FOUR

PRICE DEMAND SCHEDULES FOR VARIOUS USER CATEGORIES

This chapter addresses the second and third objectives of the study. In the first instance the demand schedules/curves for the various user categories are derived. These demand curves were used firstly as a base from which the use side mathematical equations were derived and secondly to determine the various values of water.

4.1 GENERAL CONCEPTS

The main objective of this project is to determine the economic value of water in the Vaal River. The study by Gibbons[11] (1986) was used as a main theoretical reference for this purpose and provides the basis for the discussion that follows. In the absence of working markets in the Vaal catchment for water and with the growing conflict over water use, there is a pressing need to understand the underlying economics of water demand and value in various economic sectors. In addition, marginal benefits of water use should be compared to marginal costs of proposed water supply projects in the interest of promoting economic efficiency and fiscal responsibility.

The price of water is loosely defined as the maximum amount the user would be willing to pay for the use of water. Price is used as a proxy for value. In the absence of market clearing prices, there are a number of alternate means of estimating the value. First, there may be some evidence of market-like transactions within a given sector. Payments of this kind for water indicate that the user is willing to pay at least a certain sum, which amounts to a lower limit on value in that sector.

More complete demand information may be represented in a formal demand curve for a particular use. If enough price/tariff and quantity data are available, a water demand curve can be estimated, from which, in turn, estimates can be made of marginal values of the resource use at different quantities demanded.

Financial budget information on a single productive process can also be used to impute a share of total product value to the water input. If all factors of production are paid at their marginal productivities, the residual, after subtraction of all other inputs, is assumed to be the maximum economic return to the water input.

Without actually studying demand relationships, the concept of alternate cost can also be used to value water. The cost of the least expensive alternative to water

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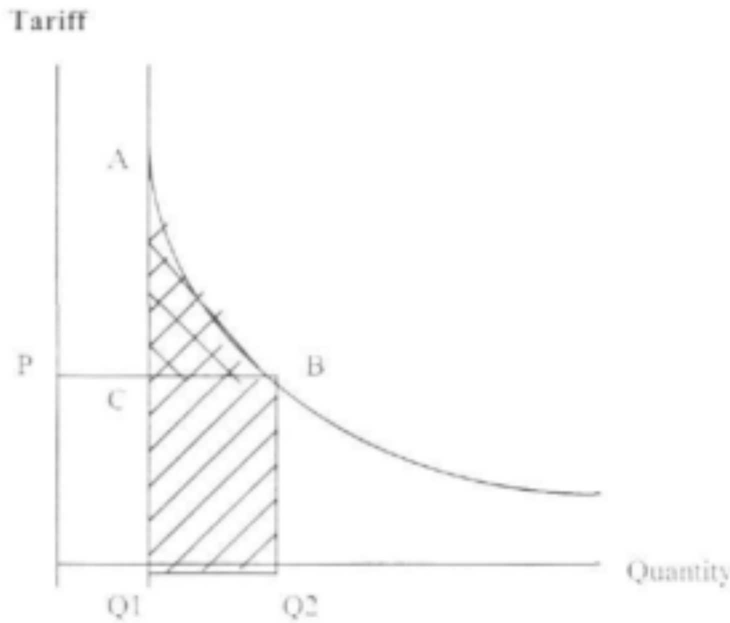
11 Gibbons, D. C., 1986, 'The Economic Value of Water', *A Study from Resources for the Future*, Washington DC, The Johns Hopkins University Press.

serves as a proxy for the maximum amount the user might be willing to pay for water.

The economic value of total water use is derived from the demand curves for the various use sectors. This is illustrated by Graph 4.1:

GRAPH 4.1: CONSUMER DEMAND CURVE



The economic value of water is the total shaded area under the demand curve. The amount the consumer actually pays for the increment is the water tariff times the quantity. In Graph 4.1, total willingness to pay is represented by area ABQ_2Q_1 while the consumer actually pays only CBQ_2Q_1. In the practical calculation of these total values, the integral was calculated under the curves, from the current quantity (Q_2) at tariff P (coordinate B) by the consumer in this case, until the point where the curves became inelastic. That is, where the marginal changes in demand due to tariff increases, started to become zero.

The individual demand curve and the economic value of water derived from the demand curve have been explained above. The total economic value of a specific use sector can now be estimated by multiplying the economic value of a sectoral unit (e.g. household) by its "driver" (e.g. population). The demand curves for the main use categories will be discussed below.

4.2 SPECIFIC DEMAND SCHEDULES/CURVES

The aim of this section is twofold, namely:

1. To derive demand functions of water for the Vaal River system Area, for the various user categories; and
2. To calculate price/tariff elasticities of demand for water, in order to determine how responsive water demand is to changes in tariff.

   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. price/tariff) of the commodity (Common, 1995)[2]. Also see Table A.2.2.2, Annexure 2.2 in this regard. In this exercise a retail water tariff was used as a proxy for price.

Due to the methodology used to derive the demand curves the resultant curves mathematically extend to infinity. The reader should therefore note that it is unrealistic to extend pricing scenarios to extreme ranges of the curves. In practice one would never logically consider tariff changes of this magnitude, and statistically it is incorrect to make estimations beyond the range of the variation of the variables used to estimate the original function. For example, if the range of tariff fluctuations for the observed values during the sampling period was 50 percent, then demand estimates should not exceed this range from the current tariff. Demand changes following tariff changes should, therefore, only be estimated within a reasonable range of the prevailing tariff.

4.2.1 **Households**

The main aim of this section is to derive the household demand function based on consumer behaviour in order to calculate price/tariff elasticities of demand for water.

Methods available in this regard are the following:

- **Contingent Valuation**

  Information is obtained by means of questionnaires. The first step is to establish a typical user profile. After this, the effect that a tariff increase would have on such a user's consumption patterns is determined.

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[2] Common, M., 1995, 'Sustainability and Policy. Limits to Economics', Cambridge University Press. p 121.

A shortcoming of this method is that outcomes are not actually observed, but are based on expectations.

This method was used by Veck and Bill (1999)[23] to determine the price tariff elasticity of demand for water in the Vaal River supply area.

- **Time Series Analysis**

  Here tariff and demand data are compared over time in order to determine a relationship between them.

  A shortcoming of this method in South Africa is that there is very little variance in historic tariffs; further, during periods of drought when tariff was used to regulate volumes of water used, it was done mostly in conjunction with direct control measures.

- **Cross Sectional Analysis**

  The reaction of different users to different tariffs at the same point in time is investigated. An example of this is where a relationship is determined between consumption and tariff data for different municipalities. An advantage of this method is that many factors influencing water consumption can be simultaneously analysed through multi-regression analysis.

For purposes of the study, the cross sectional analysis method was preferred as the contingent valuation approach has already been applied in South Africa while time series analysis could not be used due to data limitations.

In order to determine price tariff elasticities of demand for various income levels, data were collected from a cross sectional sample of 13 local authorities in Gauteng. It was assumed that this sample could be regarded as representative of the study area.

Although the data thus collected, is indeed the best available, it is still inadequate in some respects (See discussion in Annexure 4). In order to eliminate this current data vacuum, it is important to note that local authorities should be keeping these type of records more scientifically for research purposes.

THEORETICAL FRAMEWORK

The main aim of this section of the study is to derive the domestic demand function to calculate price tariff elasticities of demand for water[24]. Classical

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23 Veck, A. and Bill, M., 1999, The Water Research Commission Project K5/90. Price Elasticity of Demand for Water Survey no. 2 Report (CV experiment).

consumer theory predicts that a consumer's demand is a function of price (tariff) and income. More specifically, when considering water demand, this function has been expanded to include influencing factors such as:

- Climate (i.e. temperature, rainfall)
- Regional variation[2)]
- Supply variance (i.e. supply uncertainty)
- 'Some measure of real estate' (e.g. housing space) (Turnovsky, 1969)[3)]
- Erven size
- Property value – used as a proxy for housing space (mentioned above).
- Socio-economic conditions
- The number of persons per household
- The percentage of persons per household under 18 years[4)]
- Existence of own water supply e.g. boreholes.

In determining the 'price/tariff elasticities of demand for water' this study is essentially attempting to isolate the *tariff effect*. In order to be able to concentrate on this *tariff effect*, many of the above listed variables have been assumed constant across the entire sample[5)]. This has been made possible by geographically restricting the study.

Restricting the study to the local authorities within the Vaal area at a specific point in time (1998) allows us to assume that the socio-economic profiles, weather patterns, hydrological factors, supply variability, and residential, commercial and industrial shares of total water use within each municipality are similar (Gibbons, 1986). Hence, of the variables listed above, only tariff, income, property value and erven-size have been included in the demand function. The demand function therefore takes the following form:

$$\mathbf{Q \quad = \quad b_0 - b_1T + b_2I + b_3PV + b_4E}$$

Where:

- Q = Quantity of water demanded per capita per year, in Kilolitres.

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1) Estimating a demand function for water is extremely difficult because it is determined by many non-economic factors that cannot be included in the model (Turnovsky, 1969).

2) Foster & Beattie (1979) showed that water demand is more price elastic in areas where outdoor water use forms a larger fraction of total water use (e.g. arid areas).

3) Turnovsky, 1969. Ibid

4) One would expect per capita water use to be higher in areas with a large percentage of children (Turnovsky, 1969, p 352).

5) This technique has been used by a number of authors some of which include: Foster and Beattie (1979) and Döckel (1973).

- T = Average tariff of water[6], given by total water demand divided by total amount billed, in Rands per Kilolitre. An average tariff is justified because even though a block-rate structure exists, the majority of households fall within the first consumption block, thus minimising the loss of accuracy by not using marginal tariffs[7].

- I = Average income, given as average annual per capita income in Rands.

- PV = Average property value, given as the average of the sum of the value of the stand plus any improvements, in Rands.

- E = Average erven size in m^2.

Theoretical expectations for the signs of each of these variables are:

- The intercept term ($\mathbf{b_0}$) should be positive because water is essential for life, therefore consumers will always have positive consumption.
- The coefficient for water tariff ($\mathbf{b_1}$) should be negative. Demand theory based on observation and empirical research, predicts that as the price tariff of a commodity increases, the quantity that an individual will demand will decrease.
- The coefficients for property value ($\mathbf{b_3}$) and erven size ($\mathbf{b_4}$) should both be positive. Property value is used as a measure of the amount of real estate a consumer has. According to Turnovsky (1969, p 352), the more real estate a consumer has, the more water-using appliances they will have. Hence it can be expected that people with higher real estate values (property value) will have higher demands for water. The size of a consumer's property (erven) should give an indication of the size of the garden. One might therefore expect more water to be demanded on large properties as opposed to small properties.
- The income coefficient $\mathbf{b_2}$, should also be positive, since it is expected that as income increases water demanded will also increase.

Questionnaires (Annexure 4.1, Table A.4.1.2) were sent to these local authorities and were explained to respondents by means of telephone conversations as well as personal visits in some cases. The following basic information was required:

(I) CROSS SECTIONAL DATA (for 1998)

[6] See Gibbons (1986) page 14, who refers to Billings and Agthe's study in 1980, for a discussion on the advantages and disadvantages of using average price rather than marginal price. Hanke (1970), however, is also quoted in Gibbons (1986) to show that water demand is influenced by marginal tariffs.

[7] According to Gibbons (1986) most residential water demand studies have made this, or similar assumptions and have used average prices as well.

(i) The total **volume** of water consumed (kl):
(ii) The **monetary** value of the volume in (i):
(iii) An indication of the size of the **population** involved:
(iv) Average **property values** (stand plus improvements) and
(v) Average **size of erven**.

(II) TIME SERIES DATA

(i) Total **volume** of water consumed per year.
(ii) Total **monetary** value of water in (i).

It should be noted here that the assumption was made that tariffs could serve as a proxy for price. It was further assumed that the same proportion of households in each category would pay their municipal water accounts and that payment is not tariff-sensitive.

The next step was to calculate elasticities for the various income groups namely Upper-Middle and Lower income levels, where Upper-Middle income refers to the category of incomes above R26 900 per annum (1998 tariffs) and Lower incomes are below R26 900. These income levels were calculated using the Social Accounting Matrix compiled by Conningarth Economists[4]. This was done by first estimating demand equations relating use to tariff (proxy for price). These relationships were determined statistically by means of multiple regression analysis. This procedure allows the incorporation of the effects of several causal factors (as indicated in (i)-(v) in (I) above in the relationship. The procedure followed is discussed in detail in Annexure 4.1.

As far as the derivation of elasticity is concerned, previously only two major studies, namely Döckel[5] (1973) and Veck and Bill[6] (1999), have been done on this topic in South Africa. The overall price/tariff elasticity of the demand for water obtained for this study was –0,58. It compares fairly closely with the figure of –0,69, for white households, calculated by Döckel. However, it differs significantly from the elasticity of –0,17 obtained by Veck and Bill. This discrepancy can mainly be attributed to a difference in elasticities for the lower income groups. A very high elasticity resulted for the low income group in this study, namely –1,12, whilst the Veck and Bill study obtained a relatively inelastic value of –0,14.

4) Internal document of Conningarth Economists.
5) Döckel, J.A., 1973, "The Influence of the Price of Water on Certain Water Demand Categories, *Agrekon*, Vol. 12, No.3, pp 17-22.
6) Veck, A. and Bill, M., 1999, The Water Research Commission Project 790/1/00. Price Elasticity of Demand for Water Survey no. 2 Report (CV experiment).

The major difference in the figures is probably attributable to the fact that the elasticities calculated in the present study, should be viewed as long run elasticities. Cross sectional analysis has been used to capture the consumer behaviour embedded over a long period. Veck and Bill used the contingency valuation method which, owing to the nature of the technique, measures short term elasticity.

The overall elasticity result of –0.58 is also similar to the results of other international studies. The elasticities of the various income groups were as follows:

Description of Group	*Elasticity*
Upper Middle Income Group	-0.35
Lower Income Group	-1.12
Combined Income Group	-0.58

Since the elasticity derived for the upper income group had the wrong sign, the elasticity for the middle income group was used as a proxy for the upper and middle income groups. The demand for water in the lower income group was very elastic, namely a 10 % increase in tariffs would lead to a 11.2 % decrease in use.

In order to split the income categories above between indoor and outdoor use, information was taken from the study of Veck and Bill. The results were as follows:

Upper/Middle Income Group	
Total	-0.35
Indoor	-0.26
Outdoor	-0.91

Lower Income Group	
Total	-1.12
Indoor	-1.12
Outdoor	-1.52

The assumption was made that the elasticity for parks would be the same as that for the outdoor category of the upper middle income group.

Note that these elasticities deviate from those calculated by Mr Russell Wise in Annexure 4.1 for a research project for his masters degree at the University of Pretoria. Greengrowth Strategies cc. recalculated these elasticities using log-log functions. This was used in order to derive non-linear demand schedules for these categories. An advantage of this estimation method is that the elasticities are directly obtained from the equations and need not be calculated as in the case of linear regression.

The demand curves derived for the various household categories are depicted in Graphs 4.2 - 4.5 below. For a more detailed discussion of methodology and results, see Annexure 4.1.

It is important to interpret these graphs. The following aspects should be noted:

- In most studies the researcher probably will not estimate a price/tariff demand curve himself but will make use of secondary information. To construct a price/tariff demand curve for his specific project he needs the current tariff as well as the average consumption of the category of a water user for a specific period (per month). Further he also needs the price/tariff elasticity for that specific category.
- The demand curve is constructed by assuming that the value of the last unit of water consumed is equal to the tariff paid by the consumer. The highest quantity lowest value coordinate (the rightmost coordinate on the graph) represents the current tariff. For example, in the case of Graph 4.2 it equals R2,96/k*l*. The demand curve is drawn by using the price/tariff demand elasticity with the rightmost coordinate on the graph (R2,96 at 61 k*l*, the average consumption of this group per month) as a starting point.
- The total economic value for water (per capita per year) can be defined as the total area under the curve, between the rightmost coordinate and where the curve becomes inelastic (i.e. marginal change becomes zero). Only this portion of the curve can be used for analytical purposes due to the reasons already given in Section 4.2. In Graph 4.1 it is represented by the area ABQ2Q1. The value can be derived by calculating the integral under the price/tariff demand curve. To obtain the value per cubic metre of water, the total value should be divided by the volume of water use. With regard to Graph 4.1, the quantity of water consumed totals 61 kilolitres per capita per year.
- For example, in the case of Graph 4.2 for the use sector, Households: High Income: Outdoor the value at retail point was R8,94 per m^3. It is important to note that this figure differs from the economic values indicated in Graph 4.2 and Table 5.1, the reason being that it refers to the retail value to the user (purified water on tap) while the figures in Graph 4.2 and Table 5.1 refer to the economic value for raw water at the source.
- In the case of Graph 4.2 the value of raw water at the source was derived at as follows:

• Actual average tariff/m^3 paid by consumer	R 2,96
• Value of water at retail point:	

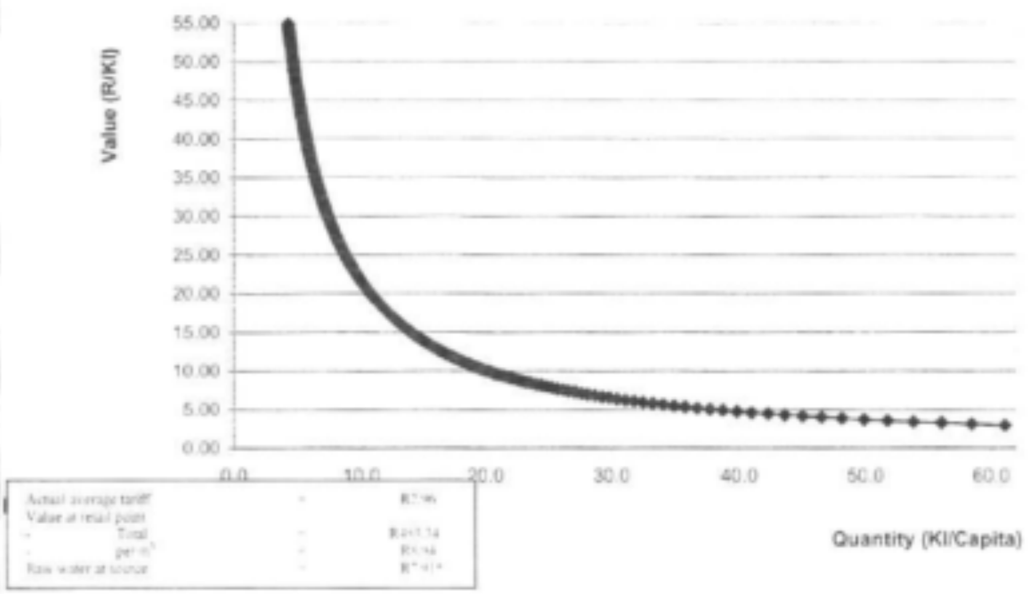
- Total	R483.43
- Per m^3	R 7.97
Minus purification and distribution costs	R 1.03*
• Value of raw water at source	R 6.94

* used for all household categories.

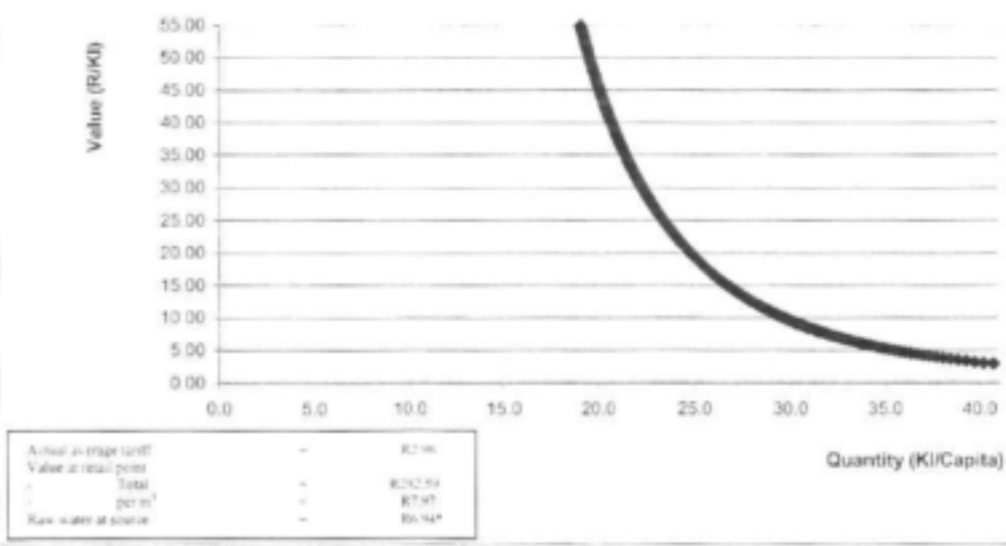
The same principle was followed in all other household use sectors. In the case of the Electricity, Irrigation and Heavy Industry sectors, purification and distribution costs were not applicable and the value of raw water at retail point was, therefore, directly calculated.

- The elasticity component of each demand curve should be interpreted as follows: A higher elasticity will yield a demand curve with a lesser slope and implies a greater reduction in use in relation to a change in tariff. These elasticities were estimated, making use of a log-log function approach. This ensured that the arc elasticity was constant at all points on the demand curve.

Graph 4.2 : Demand Curve : Households: High Income : Outdoor

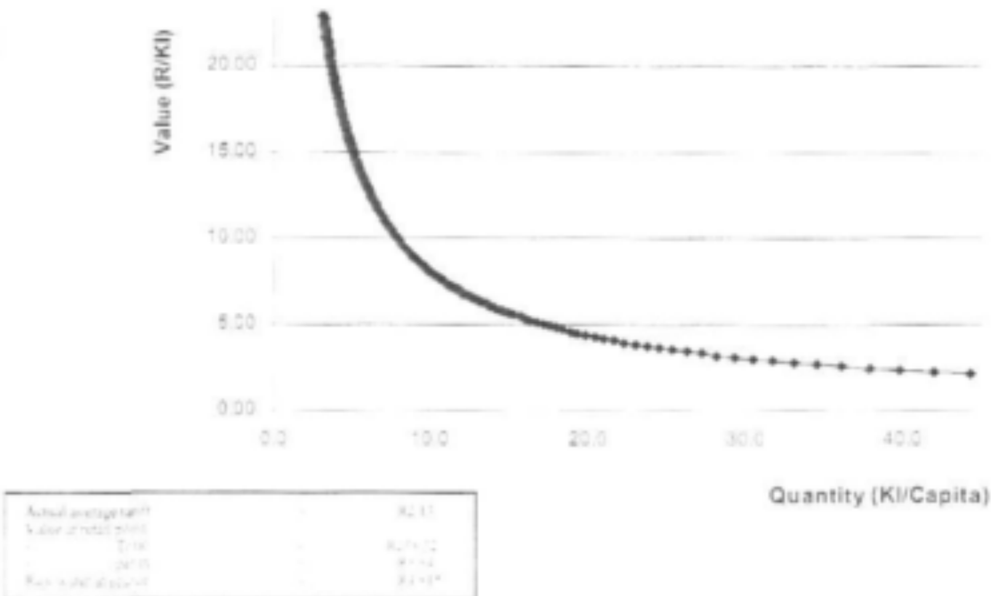


Graph 4.3 : Demand Curve : Households: High Income : Indoor

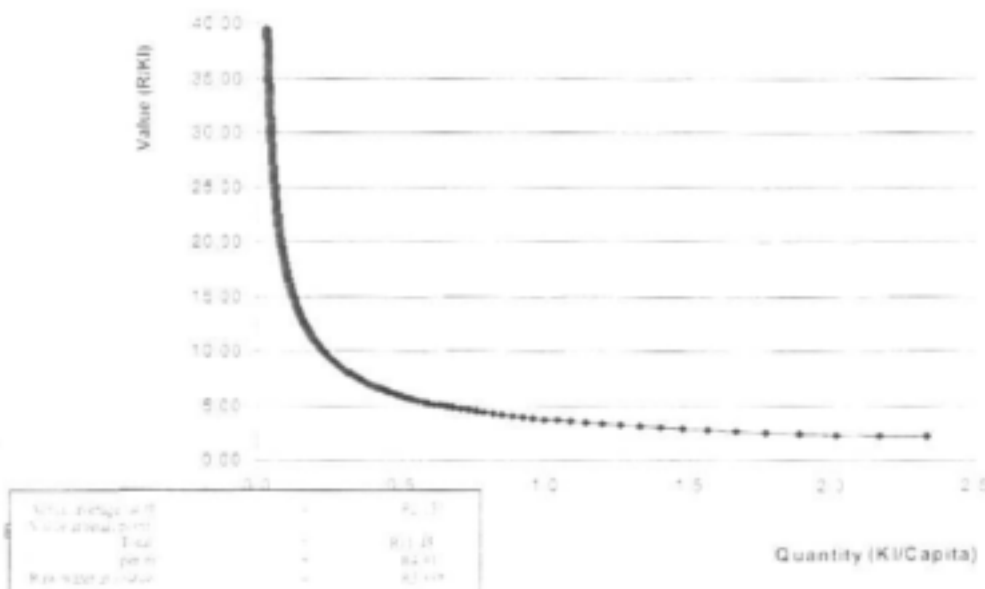


* This figure was calculated by subtracting purification and distribution costs of R1.03 from the value directly above it.

Graph 4.4 : Demand Curve : Households: Low Income : Indoor



Graph4.5 : Demand Curve : Households: Low Income : Outdoor



* This value was calculated by subtracting purification and distribution costs of R1.03 from the value directly above it.

4.2.2 Irrigation Use

To derive a demand schedule for this category, it was necessary to determine a net income (NI) for farmers in the study area by means of a farm income and cost analysis. It was decided to take the Vaalharts[1] area as a sample to represent the total study area. It should be noted that this extrapolation could represent an over estimation of the value of water for irrigation purposes: This is due to the fact that the Vaalharts scheme was still during 1999 mostly a gravity water supply scheme with relatively low costs and higher productivity. This is probably not the case in the rest of the study area, where irrigation takes place on an ad hoc basis, pumping directly from the river.

A NI was calculated for this area making use of the so-called "budget approach"[2]. The basis for this estimation was a study done by Viljoen, Symington and Botha, Department of Agricultural Economics of the University of the Free State (1992)[3].

In order to reflect the current (1999) situation all data in this study were updated with the help of officials from Senwes previously known as the Sentraal Wes Cooperative.

For this exercise the five dominant crops on the Vaalharts scheme were identified (maize, wheat, peanuts, cotton and lucerne). The income and production cost per crop per hectare was calculated and is presented in Table 4.1.

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1) The reader is reminded that the "Middle Vaal" as defined in this study, includes magisterial districts that are commonly considered to be part of the Lower Vaal catchment.

2) The budget approach refers to the value of water as a resource to farming. The total crop revenue less non water input costs generates a residual, the maximum amount the farmer could pay for the water and still cover costs of production. It thus represents the on-site value of water.

3) Viljoen, F.F., Symington, H.M., Botha, S.J. Verwantskap tussen waterbeperkings en finansiële gevolge in die Vaalrivier watervoorsieningsgebied met spesiale verwysing na besproeiingshoerderye in die Vaalharts gebied. WNK verslag 288/92, Bloemfontein, 1992.

TABLE 4.1: REVENUE AND DIRECT PRODUCTION COSTS OF DOMINANT CROPS IN THE VAALHARTS IRRIGATION SCHEME (RAND PER HECTARE, 1999 PRICES)

Crop	Wheat	Maize	Peanuts	Cotton	Lucerne
Gross turnover					
Product	6 113	5 219	8 406	9 061	6 829
Hay	351		699		
Total	6 464	5 219	9 105	9 061	6 829
Direct production cost					
Seed	509	277	801	175	952
Fertilization	984	787	480	768	353
Weed killers	75	138	186	38	0
Pesticides	79	267	295	909	52
Crop spraying cost	57	58	0	232	0
Crop insurance	336	167	273	1 631	0
Electricity & water	210	255	255	210	620
Tillage cost	350	282	342	375	186
Interest on production cost	234	201	237	390	0
Harvesting cost	520	711	849	1 427	690
Total	3 358	3 144	3 719	6 158	2 856
Gross Crop Income	3 106	2 075	5 386	2 903	3 973

It was established that the average plot size per farmer is 82.9 hectares. However, due to the fact that double cropping takes place the actual hectares cultivated per farmer adds up to 109.3 hectares.

Table 4.2 gives a breakdown of the crops, hectares and gross crop income used to calculate the gross farming income per unit.

TABLE 4.2: CALCULATION OF GROSS FARMING INCOME

		Gross Farming Income	
Crop	Hectares	Rand per hectare	Total per farm unit
Wheat	36.8	3 106	114 305
Maize	26.5	2 075	54 983
Peanuts	21.5	5 386	115 799
Cotton	10.2	2 903	29 610
Lucerne	14.3	3 973	56 813
Total	**109.3**	**3 399**	**371 511**

The gross farming income per hectare is expressed in relation to the total hectares cultivated (including double cropping). For purposes of recalculating it to the actual farm size this amount has to be multiplied with the factor:

$$\frac{109{,}3}{82{,}9}$$

The gross farming income per hectare is now R4 480.

The gross farming income per farm unit was calculated as R371 511. To arrive at a net farming income the following fixed costs were subtracted:

- depreciation
- fixed labour
- maintenance
- insurance
- electricity, and
- sundry.

To arrive at net income (NI) the following cost factors were deducted:

- interest on depreciative capital, and
- owners salary.

To calculate depreciation and interest on depreciative capital a capital investment structure per average farm unit excluding land values was developed.

As a result of the fact that interest on all depreciative capital has been calculated the actual debt of farmers was ignored. Table 4.3 shows the amounts used in calculating the NI per average farm unit.

TABLE 4.3: CALCULATING OF NET INCOME FOR THE AVERAGE FARM UNIT

		Total Farm Unit	Per Hectare
		Rands	Rand/Ha
Gross turnover per hectare		**762 044**	**9 190**
Minus direct production cost		390 533	4 710
Gross Farming Income		**371 511**	**4 480**
Minus Fixed Costs:			
- Depreciation	48 578		
- Fixed labour	42 140		
- Maintenance	10 824		
- Insurance	6 921		
- Electricity	10 469		
- Sundry	6 882	125 815	1 517
Net Farming Income		**235 696**	**2 963**
Minus:			
- Interest on depreciative capital	41 547		
- Owners salary	89 073	130 620	1 575
Net Income (NI)		**115 076**	**1 388**

The value of irrigation water was calculated by deducting the net income of dryland for the area from the NI as shown above. The results are as follows:

	Rand/hectare
Net income (NI)	1 388
Minus Net income of dryland[21]	250
Net income (NI) of irrigation	1 138

The next step is to calculate the rental value of irrigation water. This was done by dividing the NI per hectare by the amount of water allocated per hectare. The water allocated per hectare is 7857 m^3 therefore the average rental value of water is:

$$\frac{1\,138}{7\,857} = 14.48 \text{ cent } m^3$$

Establishing a demand curve

21 This amount is an estimation by Senwes officials.

For the establishment of a demand curve the average rental value of water as calculated above is important. However, on the other hand, the deviation of the NI for the various farmers is also of equal importance.

As far as the deviation is concerned the research of Viljoen, Symington and Botha[5)] was accepted. Their analysis assumed the revenue and direct costs for the various crops would be very similar for the different farmers. However, the fixed costs, interest on depreciative capital and owner's salary differs between different categories of farmers. In their research they have established a standard deviation per fixed cost item. These standard deviations were used to calculate an overall standard deviation by using the fixed costs items as indicated in Table 4.3. This results in an overall standard deviation of R141,4 per hectare or 1,8 cents/m^3 water use.

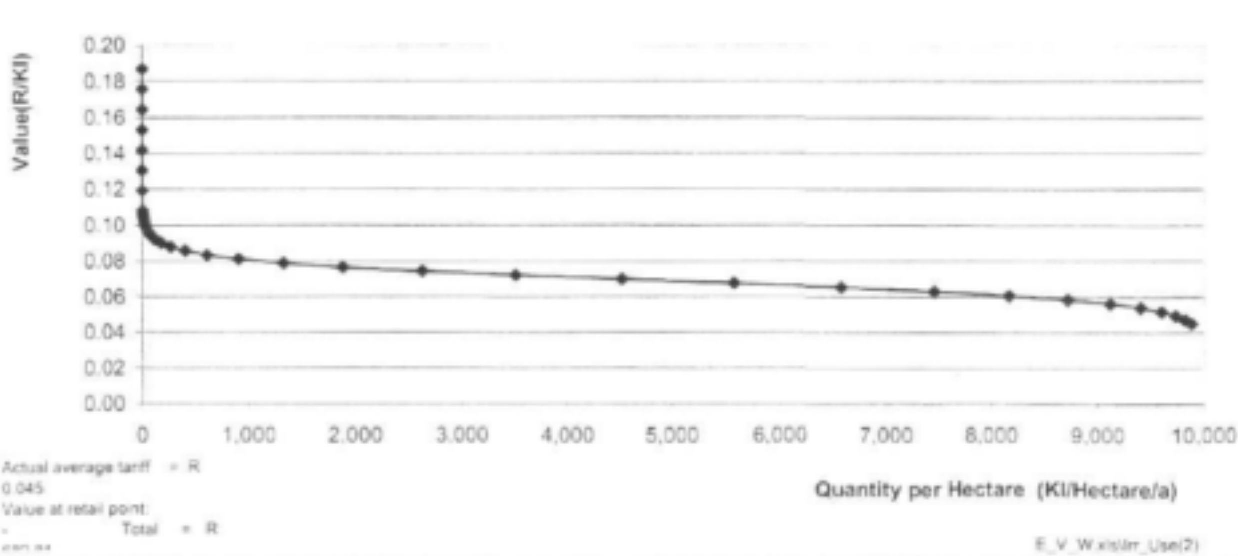
Based on a mean rental value of 14,48 c/m^3 and a standard deviation of 1,8 c/m^3 a smoothed cumulative distribution was generated and a non-linear equation (logit transformation) was fitted to this distribution. This mathematical equation was then used to represent the demand curve component for irrigation water. The regression analysis used to calculate the demand schedule is shown in Annexure 4.2. The demand curve derived from this regression analysis is shown below in Graph 4.6.

Limitations in methodology used

In Chapter 2 it was already mentioned that the quality of irrigation water is very low and that the model does not make provision for quality differences in water. It should be noted that different qualities of water would have resulted in different values of water.

It is also important to note that in the Upper Vaal area sprinkle irrigation, directly from the river, is mostly used while the Middle Vaal (specifically the Vaalharts scheme) still uses flood irrigation to a large extent although a gradual change over

Graph 4.6 : Demand Curve : Irrigation



*No purification and distribution costs applicable.

4.2.3 Industrial Use

The budget approach was also applied to the various industries in South Africa to derive a demand curve for industrial water use. A similar approach (with minor adjustments) was used in a study by DWAF in 1991[11]. This approach differs to a large extent from the methodologies used by other researchers. The most popular methodology is to use the opportunity cost of reusing water i.e. the costs of effluent water treatment as the economic value of water (Gibbons, 1986).

The information base for the calculation was an input-output table, which reflects the value of water per sector in relation to the sector's total production cost. In theory it could be stated that the water tariff could be increased up to the point where the industry will no longer make any profits. At this tariff level, the industry will stop its production process and therefore will no longer use any water. By calculating this relationship for all the manufacturing sectors, and by doing a cross sectional analysis, a demand curve can be derived.

A problem associated with this approach is that the water tariff can be increased to absorb all the profits excluding a normal profit (normal profit already forms part of the total cost of the budget approach). In practice certain industries can easily relocate to other industrial locations in South Africa, where water tariffs are more attractive. Therefore theory and practice are not compatible. For purposes of this study, it was assumed that industries will only be willing to pay more for water in the Vaal River system if they derive a locational advantage from remaining in the area.

A study by Urban-Econ[12], focussed on why industrialists do not want to relocate to other regions or, stated differently, calculated the advantages of being in the Gauteng metropolitan area from a cost point of view.

According to this study, the advantage of location in the Gauteng area on average amounted to 5.9 % of total cost. This figure indicates the extra cost industries in the Gauteng area that are prepared to pay for the advantage of being located in the Vaal River supply area.

To assume that this 5.9 % could be utilized for water tariff increases is probably unrealistic. This is due to the existence of other cost items which are also sensitive to the relocation decision i.e. inward and outward transport cost and rent. Taking this into account, industry is probably only willing to contribute a portion of the 5.9 % locational advantage to any increase in water cost. Consequently the

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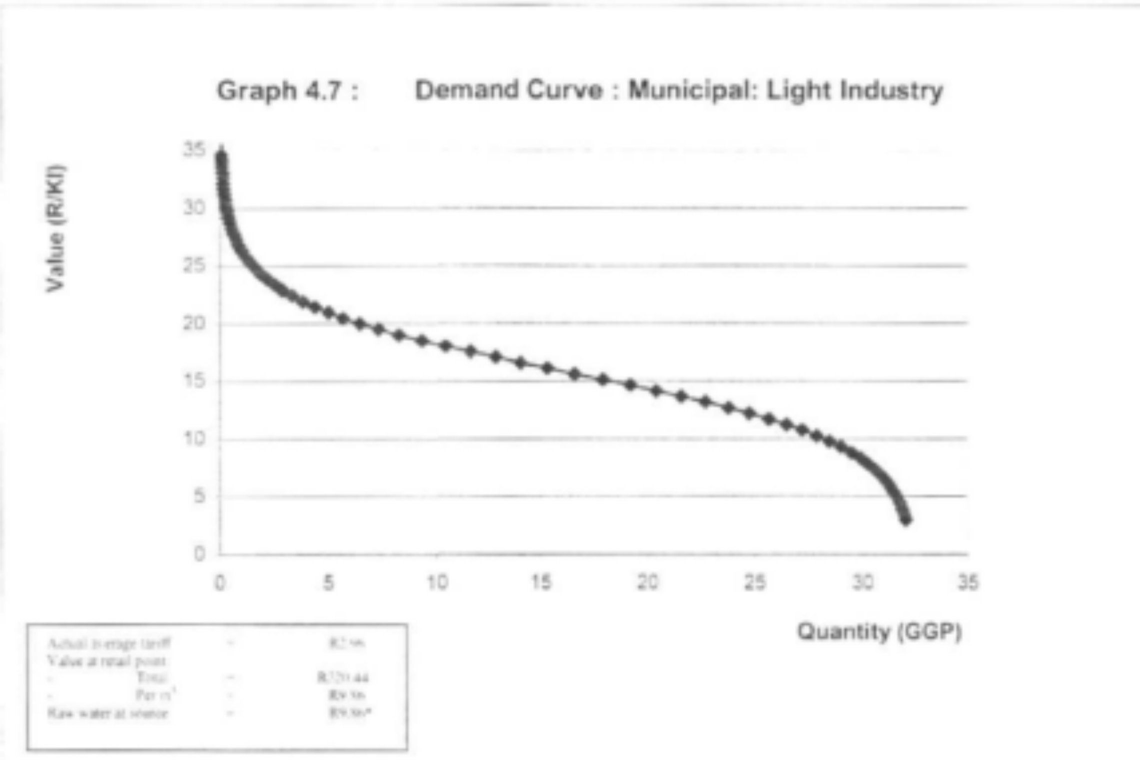
11) DWAF. The determination of the economic value of water for the Vaal River system. Urban-Econ. 1991. DWAF Report No. PC000/00/10291.

12) Source: Urban-Econ 1987. "Metropolitan location analysis in a spatial economy with a decentralization interventionist policy". Unpublished.

location advantage assigned to water in this study is only 0,2 %, as explained in Annexure 4.4.

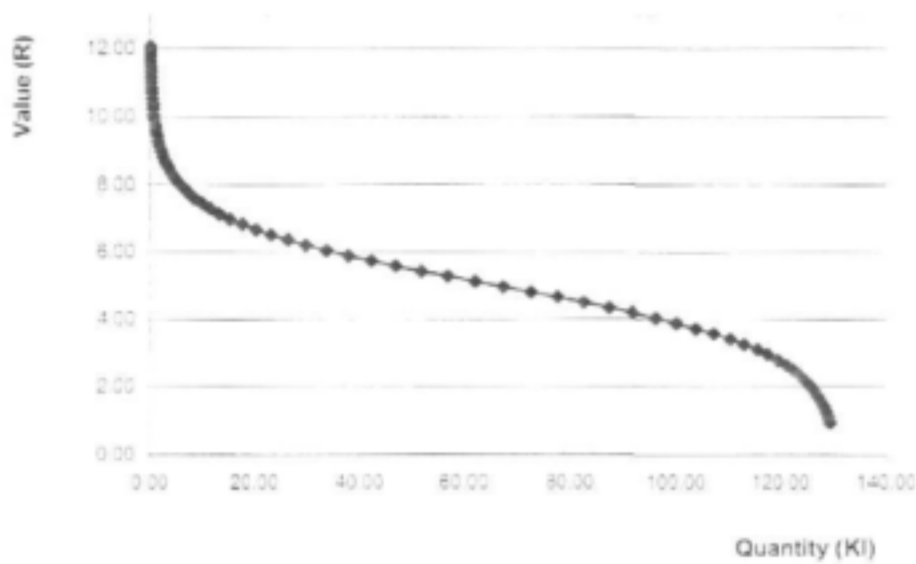
A cross sectional analysis was done for the various manufacturing industries, using the approach above. The demand curves derived for heavy and light industry are shown in Graphs 4.7 and 4.8 hereafter. It should be noted here that these graphs represent the total industry and not a specific industry. It should also be noted that most industries are very insensitive to tariff changes since the water input proportion is negligible. A detailed discussion of the methodology and calculations is given in Annexure 4.4.



Graph 4.7 : Demand Curve : Municipal: Light Industry

* No purification and distribution costs applicable.

Graph 4.8 : Demand Curve : Heavy Industry



[illegible]	[illegible]	[illegible]
[illegible]		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

* No purification and distribution costs applicable.

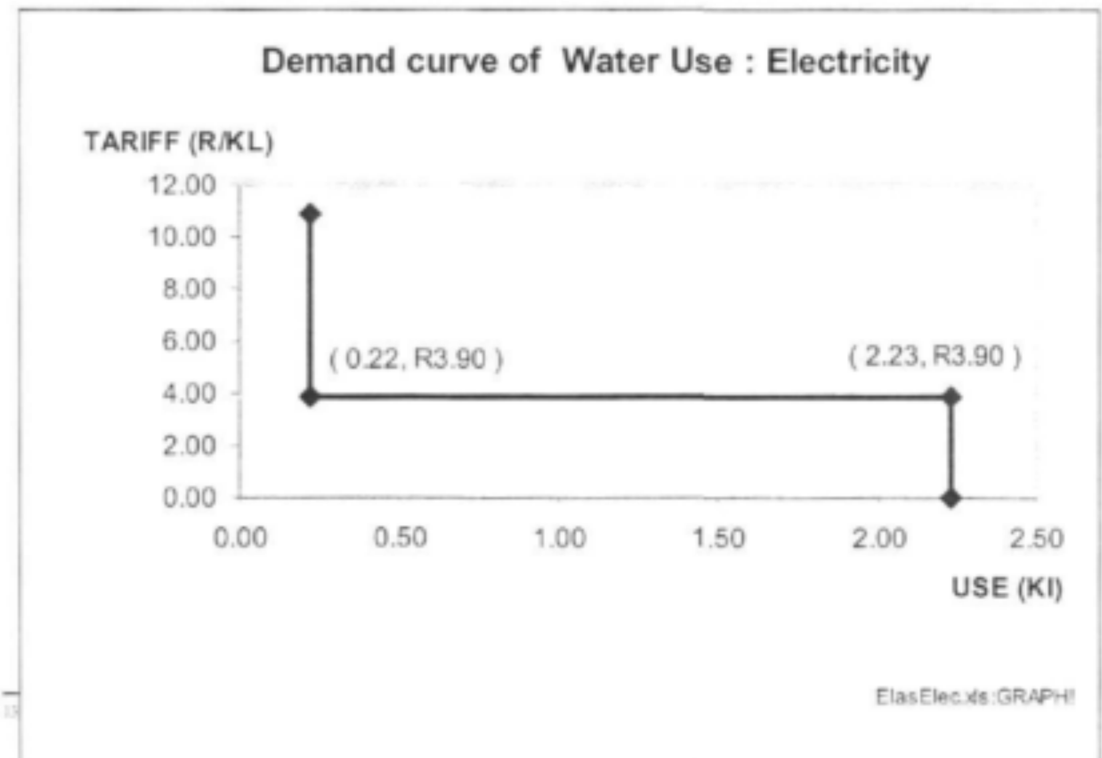
It is important to note that wet and dry industries are included in the same demand curves. It was also assumed that technology with regard to water use could not be changed. The only option open to an industry is to relocate once the water tariff becomes a deterrent. Consequently a wet industry would relocate sooner than a dry industry once the tariff of water becomes prohibitive.

4.2.4 Electricity Use

In South Africa electricity is mainly generated by coal based power generation stations. Two alternative cooling systems are used in these power stations, namely wet and dry cooling systems. A wet cooling system uses much more water than a dry cooling system to generate the same amount of electricity. In a wet cooling system ± 2.23 *l* of water is used to generate 1 kWh of electricity compared with the 0.22 *l* of water per kWh of electricity in a dry cooled system. However, building a dry cooling system is much more costly. The running costs of a dry cooling system are also slightly higher.

It is difficult and very costly to convert a power station from a wet to a dry cooling system. The demand schedule for water is therefore very inelastic. In a cost-benefit analysis done by Conningarth Consultants for the Water Research Commission in 1999[13] on dry cooling it was established that at a water tariff of R3,90 per k*l* the dry cooling process becomes the cheaper of the processes. If this information is taken into consideration it is possible to construct a demand curve as indicated in graph 4.9. In respect of this graph it should be noted that this is a dynamic model and not a static one. This graph reflects the overall picture of the industry and not that of a single power station. As tariffs increase, new power stations phased in over time will switch to dry cooling, and old wet powerstations will be replaced with dry ones or mothballed, since DWAF will not readily make water available in future to ESKOM for this purpose.

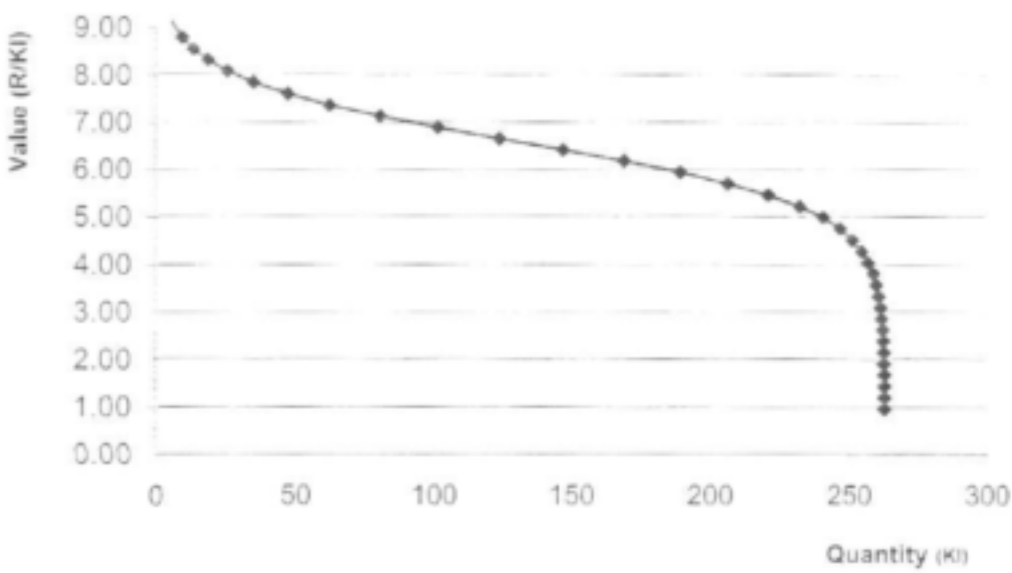
GRAPH 4.9



According to this demand curve ESKOM will continue to use water at a rate of 2.23 litres per one kWH of electricity generated if the tariff is less than R3.90 kl. Up to R3.90 kl the curve is perfectly inelastic. When the tariff goes beyond R3.90 kl, ESKOM will convert its power stations from wet to dry cooling systems. ESKOM will then only use 0.22 litres per kWh generated. If there is a further tariff increase, the curve will once again become perfectly inelastic.

As explained above the change-over process would probably be a gradual process. A more gradual change-over process was therefore generated and a smoothed curve was derived. The equation estimated to represent this smooth curve is provided in Annexure 4.5 and the curve is depicted in Graph 4.10 below.

Graph 4.10 : Smoothed Demand Curve : Electricity Use



[illegible]	=	[illegible]
[illegible]		
[illegible]	=	[illegible]
[illegible]	=	[illegible]
[illegible]	=	[illegible]

* No purification or distribution costs applicable.

CHAPTER FIVE

THE ECONOMIC VALUE OF WATER, DELIVERY COSTS AND TARIFFS

This chapter deals with objective 4, namely the comparison of the value of water with the cost per catchment.

In the first instance, the economic value of water for the various use sectors is analysed. Secondly, the supply costs of raw water, tariffs and subsidies are discussed.

The main aim is to form an opinion of the efficiency of water use, meaning the extent to which economic sectors are supported by subsidies. It should be noted again that in comparing the efficiency of water use, provision is not made for differing qualities of water.

5.1 ECONOMIC VALUE

This section discusses the economic value of water. In Chapter 4 demand schedules/curves for the various users were developed. Taking these into account in conjunction with the volume of water use in the Vaal River system, an economic value for the various users was calculated for 1998.

Average values for water use for individual consumption units in each use sector are reflected in Table 5.1. They were derived by calculating the integral for these demand curves. This boils down to calculating the area under the curve for the range of the curve over which consumer surplus is generated.

TABLE 5.1: ECONOMIC VALUE FOR WATER PER SECTOR (RAND PER M^3/A)

USER		UPPER VAAL VALUE	MIDDLE VAAL VALUE
A.	MUNICIPAL USE		
1.	Households		
	High Income		
	- Indoor	R6,94	R6,94
	- Outdoor	R7,91	R7,91
	Low Income		
	- Indoor	R4,81	R4,81
	- Outdoor	R3,88	R3,88
2.	Light industry	R9,86	R9,86
3.	Parks	R7,87	R7,87
B.	IRRIGATION USE	R0,07	R0,07
C.	ELECTRICITY USE	R6,44	-
D.	HEAVY INDUSTRY USE	R3,68	-
TOTAL			

It should be noted that although the economic values for water in Table 5.1 are identical for the Upper and the Middle Vaal study areas, they haven't actually been calculated for the different areas. Except for Irrigation, the values were calculated for the Upper Vaal area only and then inferred to the Lower Vaal area. In the case of Irrigation a value was calculated for the Middle Vaal area only and then used as a proxy for the Upper Vaal area. If separate values had been calculated, they would have differed, because of the different user group sizes.

In Table 5.2 the economic value of water for 1998 is given for the Upper, Middle and Total Vaal River systems.

The economic value of water excludes a value for afforestation. The reason for this is that the mathematical model, at this stage, treats forestry as an exogenous variable. This implies that there is no behavioural equation included in the model relating afforestation to a tariff variable. Afforestation is a relatively insignificant component in the total use of water in the Vaal River system.

TABLE 5.2: THE ECONOMIC VALUE OF WATER IN THE VAAL RIVER SYSTEM (1998)

[R millions]

Use sectors	Upper Vaal System	Percentage distribution	Middle Vaal System	Percentage distribution	Total Vaal System	Percentage distribution
Municipal use	**9,335**	**80.8%**	**1,607**	**93.0%**	**10,942**	**82.4%**
- Households	3,107	26.9%	535	31.0%	3,642	27.4%
High income	*2,566*	*22.2%*	*442*	*25.6%*	*3,007*	*22.7%*
Low income	*542*	*4.7%*	*93*	*5.4%*	*635*	*4.8%*
- Light industry	4,260	36.9%	733	42.5%	4,993	37.6%
- Parks	1,968	17.0%	339	19.6%	2,307	17.4%
Irrigation use	**33**	**0.3%**	**120**	**7.0%**	**153**	**1.2%**
Electricity use	**1,694**	**14.7%**	-	**0.0%**	**1,694**	**12.8%**
Heavy industry use	**484**	**4.2%**	-	**0.0%**	**484**	**3.6%**
Total	11,547	100%	1,727	100%	13,274	100%
Percentage distribution	87.0%		13.0%		100%	

Table 5.2 shows that the economic value for the total Vaal River system is R13.3 billion. Of this total the contribution of the Upper Vaal is R11.6 billion (87 %) and that of the Middle Vaal R1,8 billion (13 %). It is important to note that this is a flow variable, i.e. it is a recurrent value.

In Charts 5.1 a and b and in Table 5.2 the sectoral contribution is given. From Chart 5.1 it is evident that municipal use is by far the most prominent sector, contributing 81 % in 1998 in the Upper Vaal. In the Middle Vaal municipal use in terms of economic value is also dominant (93 %), although the most water used (physical units) is by irrigation. (See Chapter 3, Table 3.11).
Chart 5.2 compares the economic value of water in the total Vaal River system in

Chart 5.1a: ECONOMIC VALUE PER USE COMPONENT: UPPER VAAL

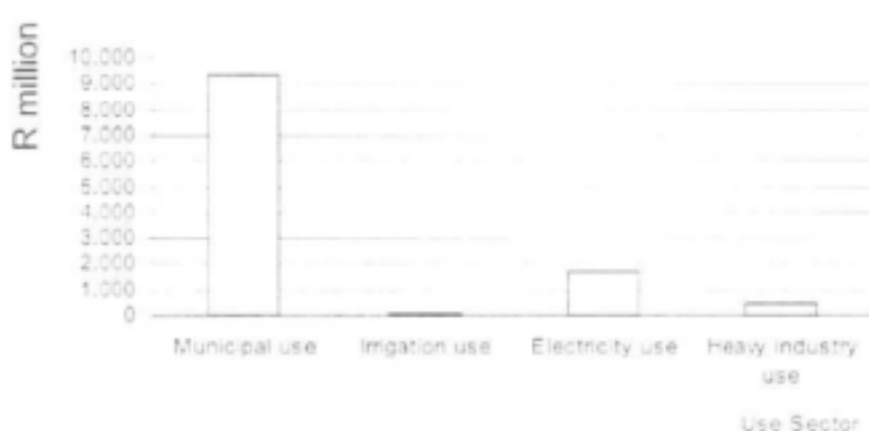
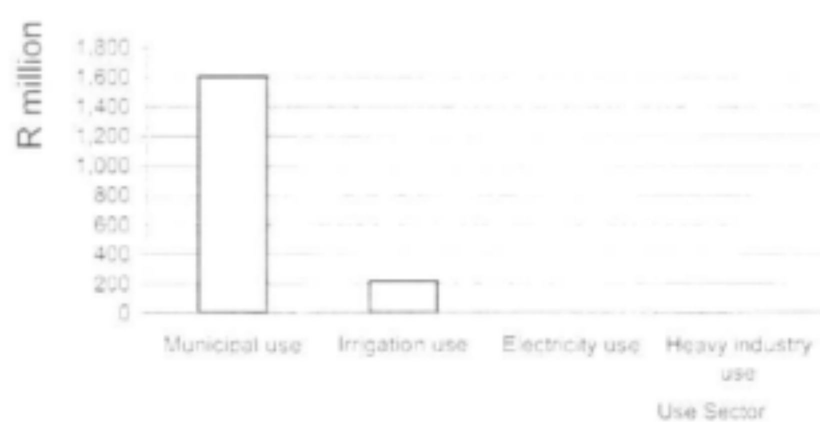
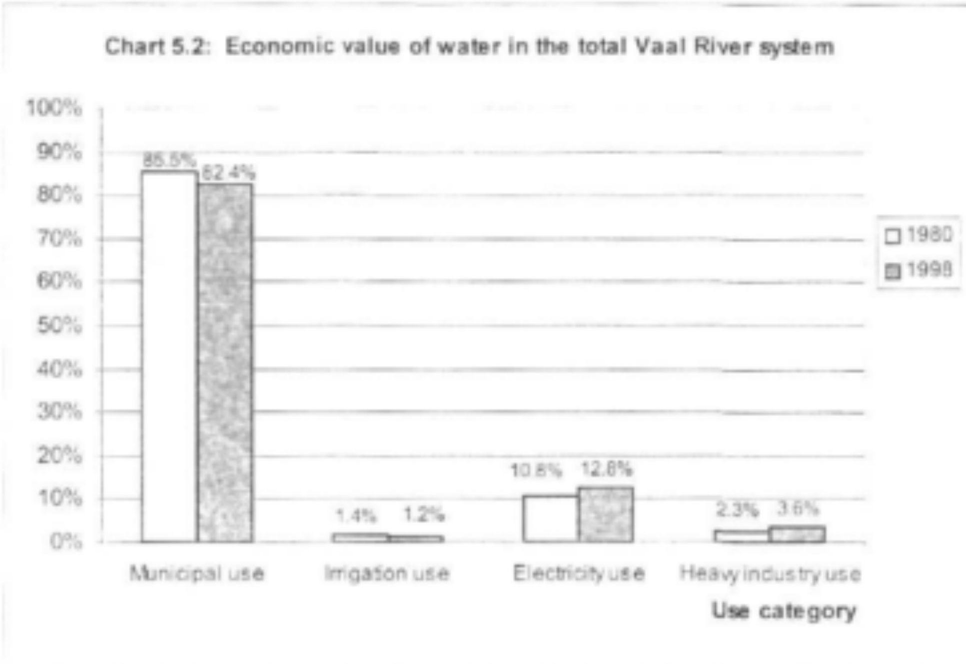


Chart 5.1b: ECONOMIC VALUE PER USE COMPONENT: MIDDLE VAAL



1980 and 1998. Note that both these graphs are in constant 1998 prices. The decrease in the share of the municipalities and the decrease in the contribution of the irrigation sector are noteworthy.



5.2 DELIVERY COSTS, TARIFFS AND SUBSIDIES

In this section, the costs of raw water delivery to the various use sectors are analysed. Raw water has already been defined in Section 2.1.2 as water in the dam or river before purifying or bulk distribution costs are added. In Annexure 5.1 the new water tariff policy for South Africa is discussed. This new strategy forms the basis of the water delivery costs and tariffs that were used in the study. Unfortunately, it was not possible to obtain historic water cost and tariff data. For purposes of the scenario modelling that is performed in Chapter 6, this is of no concern. However, in the case of the historic water resource accounts that have been discussed up to this point, the analysis could only be done in 1998 constant prices and not in current prices (tariffs prevailing in each year).

5.2.1 <u>Delivery Costs</u>

The all inclusive average delivery cost of raw water in 1998 was 57.5 c m^3 for all use sectors.

In Table 5.3 the total delivery cost per use sector is reflected for 1998.

TABLE 5.3: DELIVERY COST OF RAW WATER FOR DIFFERENT SECTORS

(1998)

[R millions]

Use sectors	Upper Vaal System	Percentage distribution	Middle Vaal System	Percentage distribution	Total Vaal System	Percentage distribution
Municipal use	654	65.4%	113	20.6%	766	49.5%
- Households	261	26.1%	45	8.2%	[illegible]	[illegible]
High income	196	19.6%	34	6.2%	230	14.9%
Low income	65	6.5%	11	2.1%	77	5.0%
- Light industry	248	24.8%	43	7.8%	291	18.8%
- Parks	144	14.4%	25	4.5%	169	10.9%
Irrigation use	120	12.0%	434	79.4%	554	35.8%
Electricity use	151	15.1%	-	0.0%	151	9.8%
Heavy industry use	76	7.6%	-	0.0%	76	4.9%
Total	1,000	100%	547	100%	1,547	100%
Percentage distribution	64.7%		35.3%		100%	

5.2.2 Tariffs

The tariff for raw water in 1998 was 94.85 c m^3 for all sectors, except for agriculture. For agriculture it was 2.8 c m^3. The surplus which results for non-agricultural water, is used to finance other expenses: The reason why there is a discrepancy between, for instance, the Households: High Income category actual retail tariff of R2.96 and the raw water tariff of 94.85 c m^3.

It must be noted that the tariff quoted is the tariff from the bulk supplier of raw water to the retailer or user, for example ESKOM.

In Table 5.4 the revenues derived from water tariffs for different use sectors are provided for 1998.

Although the revenues from tariffs imposed on raw water for irrigation purposes are very low, i.e. less than two percent for the Total Vaal system, it should be noted that the irrigation sector mainly uses water which is unsuitable for other purposes without substantial further treatment.

TABLE 5.4: REVENUE FROM WATER TARIFFS FOR 1998

[R millions]

Use sectors	Upper Vaal System	Percentage distribution	Middle Vaal System	Percentage distribution	Total Vaal System	Percentage distribution
Municipal use	**1,078**	**73.8%**	**186**	**84.5%**	**1,264**	**75.2%**
- Households	431	29.5%	74	33.8%	506	30.1%
High income	*324*	*22.1%*	*56*	*25.4%*	*379*	*22.5%*
Low income	*108*	*7.4%*	*19*	*8.5%*	*126*	*7.5%*
- Light industry	410	28.0%	71	32.1%	480	28.6%
- Parks	237	16.2%	41	18.6%	278	16.5%
Irrigation use	**9**	**0.6%**	**34**	**15.5%**	**43**	**2.6%**
Electricity use	**250**	**17.1%**	-	0.0%	**250**	**14.8%**
Heavy industry use	**125**	**8.5%**	-	0.0%	**125**	**7.4%**
Total	1,462	100%	220	100%	1,682	100%
Percentage distribution	86.9%		13.1%		100%	

5.2.3 **Subsidies**

In Table 5.5 the subsidies of raw water supply costs per user sector are shown for 1998. These subsidies were derived by comparing the cost of raw water to its raw water value.

Over the last 10 years DWAF has gradually phased in the policy that a specific catchment's revenue should pay for the delivery cost of the relevant water. One of the designated catchments in terms of this policy was the Vaal River and the policy resulted in revenue received from water tariffs being more than the delivery cost of the water including the cost of major water schemes.

In the case of agriculture, this appears at first glance to imply substantial subsidization as seems evident in Table 5.5. In this catchment, however, this conclusion would be misleading, as the geographic nature of the catchment means that agriculture uses "second hand" water that is of such a poor quality that it can no longer be used for any other purpose without substantial treatment. The "delivery cost" as usually calculated is thus a meaningless concept here, and should in fact be regarded as zero.

TABLE 5.5: SUBSIDIES OF RAW WATER SUPPLY COSTS PER SECTOR

(R millions)

Use sectors	Upper Vaal System	Middle Vaal System	Total Vaal System
Municipal use	-425	-73	-498
- Households	-170	-29	-199
High income	-127	-22	-149
Low income	-43	-7	-50
- Light industry	[illegible]	-28	[illegible]
- Parks	[illegible]	-16	[illegible]
Irrigation use	110	400	510
Electricity use	-98	-	-98
Heavy industry use	-49	-	-49
Total	-462	327	-135

Notes: 1. A positive figure indicates a subsidy

2. A negative figure indicates a cross subsidization

5.3 EFFICIENCY OF WATER USE

If a water use sector can derive benefits from its water use in excess of the total costs that must be incurred in delivering the water to that sector, this is defined here as an efficient water use. By contrast, if the cost of water delivery exceeds the benefits derived from its use, then this represents an inefficient water use.

The efficiency of water use was arrived at by taking the economic value of water (See Table 5.2) and subtracting the delivery cost of the raw water (storage plus transfer schemes). The delivery costs are shown in Table 5.3. The results of this calculation are shown in Table 5.6, which thus reflects the net value of water, or the efficiency of water use.

From Table 5.6 it is interesting to note that the irrigation sector is the only sector showing a negative result. However, this should be viewed in the proper perspective since most of the water used for irrigation is unsuitable for other purposes without substantial treatment.

TABLE 5.6: EFFICIENCY OF WATER IN THE VAAL RIVER SYSTEM

[R millions]

Use sectors	Upper Vaal System	Percentage distribution	Middle Vaal System	Percentage distribution	Total Vaal System	Percentage distribution
Municipal use	**8,682**	**82.3%**	**1,494**	**126.6%**	**10,176**	**86.8%**
- Households	2,846	27.0%	490	41.5%	3,335	28.4%
High income	*2,369*	*22.5%*	*408*	*34.6%*	*2,777*	*23.7%*
Low income	*476*	*4.5%*	*82*	*6.9%*	*558*	*4.8%*
- Light industry	4,011	38.0%	690	58.5%	4,702	40.1%
- Parks	1,825	17.3%	314	26.6%	2,139	18.2%
Irrigation use	**-86**	**-0.8%**	**-314**	**-26.6%**	**-401**	**-3.4%**
Electricity use	**1,543**	**14.6%**	**-**	**0.0%**	**1,543**	**13.2%**
Heavy industry use	**409**	**3.9%**	**-**	**0.0%**	**409**	**3.5%**
Total	**10,547**	**100%**	**1,180**	**100%**	**11,727**	**100%**

CHAPTER SIX

WATER MANAGEMENT SCENARIOS

6.1 INTRODUCTION

Up to this stage, the essence of this project was to determine the value of water. In this chapter certain water management scenarios based on this information, will be explored. They will be used to analyse the demand for water, water tariffs, economic value of water, and revenue from tariffs under certain demand and supply conditions.

In order to understand the mechanism of the model, it is necessary that a few implicit assumptions be spelled out beforehand:

- the model is highly dynamic in the sense that it makes provision both for changes in usage due to tariff changes and changes attributed to the increased use of water resulting from population and economic activity changes over time. Technically this implies that it allows for a shift in the demand curve as well as a movement along the curve itself. The net result for a specific year or period, is therefore attributable to a two step process. The first effect is through the elasticities of the various price-demand schedules, due to a tariff change (movement along curve). The second is due to the change in total use resulting from external forces such as population growth, and growth in economic forces (shift of curve). It is important to note that the changes in water use due to tariff changes do not take place proportionally, but in relation to the elasticities embedded in the various price-demand schedules.

- The model is structured in such a way that it gives solutions on a monthly and yearly basis. For reporting and comparison purposes, averages over specific periods were calculated. For instance the scenarios were based on averages calculated from 2000-2014.

- It is important to emphasize that this model was not based on the existence of a specific market mechanism. In theory the model is approximating the functioning of supply and use of water by various stakeholders. However, in practice a change in allocation due to a tariff change, will imply that water is leased on a temporary basis. This boils down to a temporary leasing of a water right and is not a permanent transfer thereof. It also implies that there are willing buyers and sellers.

- For analytical purposes cognisance was taken of the planned augmentation of water as envisaged by DWAF for the study area. The inauguration of Phase 1B of the Lesotho Highlands Scheme will take place in 2006. This means that water supply after this will be constant for the remainder of the simulation period. It also implies that the price-supply schedule will be inelastic. It is important to note that the supply could still vary depending on weather conditions that will prevail in the study area. Scenarios are built around wet, normal and dry cycles.

- For modelling purposes a 25 percent buffer supply has been assumed to ensure no chronic cyclical shortages of water. This quantity had been discussed with officials from DWAF and it is also in line with the projected excess supply which will exist on average over the last five years (2010-2014) of the projection period. In order to determine whether there is equilibrium, use and supply are compared. It was assumed that the system (at current tariffs) is in balance at the moment. This resulted in the standard scenario. Any changes in supply or usage conditions from this departure point will disturb the equilibrium situation. In order to restore this balance, the water tariff is changed. This will result in a different water use composition to restore the balance again.

  The concepts above can be illustrated by considering a high mortality situation (Scenario 3) the following occurs:

  - There will be fewer households over the forecast period than originally projected in the standard scenario.
  - This will lead to a lower water use (reduced shift of the demand curve to the night).
  - This will result in surplus water supply.
  - To restore the original balance, tariffs have to be reduced.
  - Increased consumption will take place (according to underlying elasticities). This constitutes movements along the price-demand schedules.

  It should be noted that this equating tariff is not determined by the usual market forces, but is used by administrators to balance the system.

- As far as the agricultural sector is concerned, the price demand schedule was not based on an actual current tariff as in the case of other users, but on the average rental value of agricultural water (see chapter 4 for detailed discussion). Due to the constraint that no additional irrigation will be allowed in the study area the model only

  allows for reduced water use in future in this sector; no sectoral increase in water use is permitted

Only a few scenarios will be developed in order to illustrate the mechanism of the model, as well as to test its reliability against economic theory and intuition. It must be noted in this regard that the model's real value will lie in the use that is made of it in future by other researchers, outside of the project team that developed it, or by water authorities.

Four scenarios will be explored, namely:

- a standard scenario (normal climate and population growth conditions)
- Scenario 1: a dry cycle
- Scenario 2: a wet cycle
- Scenario 3: high mortality.

Each of these scenarios was developed according to the following fixed structure:

- **Input**

  - **Assumptions**

    Each scenario was based on a set of assumptions. Assumptions were made in regard to the following variables:

    * **Tariff change (percentage)**
    * **Rainfall**
    * **Population**

    Note that tariff change is shown as an input here, because in the system dynamics model it is used as an equilibrating variable to balance simulated trends in supply and demand in order to prevent either water shortages or large surpluses from arising. This simulates how water catchment authorities can in future implement water demand management.

    The scenarios were compiled for the period 2000-2014 in order to analyse the future impact on certain variables affecting water demand and supply conditions. To achieve this, all the so-called exogenous variables had to be predicted.

    In connection with tariff change, it could be assumed that there was no tariff change (i.e. 0 %), a positive change or a negative change. The rainfall assumption could be one of the following: Dry, Normal or Wet. These seasons were calculated by making use of historic rainfall data. The Wet season was taken as the average of the high rainfall years. The dry season was taken as the below average rainfall years. The calculated deviations from the normal rainfall are as follows:

    Dry 6,1 %
    Wet 5,3 %

The choice for annual population growth could be between a moderate AIDS impact (1.8 % per annum population growth), or a high mortality (-1.24 %) rate.

It should be noted that for each scenario explored in this chapter, the effect of a change in one input only was tested. This, of course, implies that the ceteris paribus principle was applied. It should also be noted that any changes take place within given allocations of water.

The reader is reminded that these assumptions should be set within certain realistic statistical and economic limits. Although the model, and more specifically the demand curves, will technically be able to handle any exogenous change, large movements away from the status quo might not necessarily be statistically, politically or economically realistic. Also see section 4.2 in this regard.

- **Output**

There are two categories of output, namely:

- **Summary Statistics**:

The following summary statistics are produced (average 2000-2014):

* Total Economic Value of Water
* Economic Value of Water per cubic metre

- A detailed **output table** with economic values per use sector is.

6.2 STANDARD SCENARIO

For purposes of scenario building, it is important to create a benchmark against which other scenario results can be tested. For this purpose a standard scenario is developed in this section. In this standard scenario it is assumed that normal rainfall conditions will prevail. Please note that these scenarios are all merely illustrative and may not be realistic in all respects.

Regarding the population a growth rate with a moderate level of AIDS mortality is assumed.

A very important assumption made in this scenario is that the current tariff[13] prevailing for water is the tariff that will equate supply and demand over the analysis period. With minor adjustments and certain assumptions the model also predicts that average demand and supply will be in equilibrium over the period, taking into account a sufficient buffer to allow for dry spells.

Other assumptions are the following:

- The planned augmentation of water will proceed as envisaged by DWAF. Inauguration of Phase 1B of the Lesotho Highlands Scheme will take place as planned in this period.
- There will be no major new technological introductions in the economy which will have a significant impact on the use of water.
- As far as the population is concerned, it is accepted that it will grow at an annual rate of 1.8 % over the period. This includes a very moderate effect of AIDS on the population growth rate and a moderate migration effect.

Summary of Results

In Table 6.1 the results for the standard scenario are given. The figures below should not be confused with those given in Chart 3.2. The percentages reported in these charts are ***actual*** percentages for ***specific*** years. Those reported below are projected 15 year averages. Also note that transfers out are not reported in the table below.

13 In view of the fact that the model is in constant 1998 prices, it is accepted that the current price (tariff) will be adjusted to make provision for inflation over the period.

TABLE 6.1: STANDARD SCENARIO: RESULTS (Constant 1998 prices)

TABLE 6.1						
STANDARD SCENARIO: RESULTS (Constant 2000 prices)						
Assumptions						
- Tariff change	0%					
- Rainfall	Normal					
- Population	Growth with moderate AIDS					
Economic value of water						
- Total	R 17,777					
- Per cubic metre	R 5.22					
Use Sectors	Average water use over 15 years (million m³)	Percentage distribution of water use sectors	Economic value of water in the Vaal River System [R millions]		Total bulk tariffs [R millions]	
			Value	Percentage	Value	Percentage
Municipal use	1,806	53.0	15,133	85.1	1713	77.0
- **Households**	643	18.9	4,352	24.5	610	27.4
High income	*467*	*13.7*	*3,513*	19.8	*443*	19.9
- Indoors	187	5.5	1,297	7.3	177	8.0
- Outdoors	280	8.2	2,217	12.5	266	12.0
Low income	*176*	*5.2*	*839*	4.7	*167*	7.5
- Indoors	167	4.9	805	4.5	159	7.1
- Outdoors	9	0.3	34	0.2	8	0.4
- **Light Industries**	820	24.1	8,086	45.5	778	35.0
- **Parks**	343	10.0	2,695	15.2	325	14.6
Irrigation	1,118	32.8	178	1.0	50	2.3
Electricity	247	7.2	1,590	8.9	234	10.5
Heavy Industries	238	7.0	876	4.9	226	10.2
Total	3,408	100	17,777	100	2,223	100

From Table 6.1 the following aspects should be noted:

- The average economic value of water per annum for the period 2000-2014, is R17,7 billion.
- The average use over the period is 3.4 million cubic metres per annum, which results in an average economic value of R5.22 per cubic metre. The revenue generated by government from bulk tariffs amounts to about R2.2 billion per year.

- Municipal use constitutes about 53 % of total use and irrigation about 33 %. Regarding municipal use, the light industry component is the most important sector, followed closely by household use. In respect of high income household use, it is approximately three times higher than low income use. Although outdoor use is the more important element of high income use it is insignificant for low income use.
- Regarding the economic value of water, it is of importance to note that the percentage contribution of the individual use components differs significantly from volumes of water use. For example, irrigation contributes only 1,10 % to the economic value of water in the Vaal River system, despite the fact that it uses approximately 33 % of the water. Again the fact should be stressed that the quality of water used for irrigation is very low.
- The contribution of industry in regard to economic value (light and heavy) is overwhelming and constitutes 50 % of the total economic value of water. This aspect raises the question of whether other economic criteria, for instance the contribution to GDP and employment opportunities, should not be used to evaluate the economic contribution made by water rather than the economic value of water as defined in this study. GDP as well as employment take into account a broader effect on the economy. They also incorporate social aspects.

6.3 SCENARIO 1: DRY CYCLE

Scenario 1 depicts the situation of the study area experiencing a long dry cycle. The economic effect of this is that there will not be sufficient water for usage over the modelling period. In a real market situation the tariff of water will increase and selling of water will take place. The use sectors with low income yields will trade their water rights to other users with higher yields rather than proceed with their current activities. Table 6.2 reflects the water use situation under dry cycle conditions. In Table 6.3 the marginal effects of the dry scenario, relative to those of the standard scenario, are shown.

Note once again that this scenario is done merely for illustrative purposes and may not be realistic in all respects. Also note that it is assumed that all other factors remain the same.

The following aspects are of importance in Tables 6.2 and 6.3:

- The tariff of water will increase drastically by about 35 %.
- The average use of water has to drop by nearly 14 % to conform with the supply conditions.
- The sector that will be affected the most is the Household sector, because of the high elasticities for this sector (see Graphs 4.2-4.5).

- Although less water will be sold the revenue generated from the selling of bulk water will increase by 13,5 %. This can be attributed to the increase of 35 % in water tariff.
- The consumption in terms of volumes for Industries and Electricity has remained constant, although their percentage shares have increased slightly. The reasons for this are the low elasticities calculated for these sectors. (see Graphs 4.7-4.9).

TABLE 6.2: SCENARIO 1: DRY CYCLE RESULTS (Constant 1998 prices)

TABLE 6.2						
DRY CYCLE RESULTS (Constant 1998 prices)						
Assumptions						
- Tariff change	35%					
- Rainfall	Dry					
- Population	Growth with moderate AIDS					
Economic value of water	(Average over 2000 - 2014)					
- Total	R 15.714					
- Per cubic metre	R 5.37					
Use Sectors	Average water use over 15 years (million m³)	Percentage distribution of water use sectors	Economic value of water in the Vaal River System [R millions]		Total bulk tariffs [R millions]	
			Value	Percentage	Value	Percentage
Municipal use	1,519	51.9	13,105	83.4	1773	70.3
- **Households**	467	15.9	3,194	20.3	664	26.3
High income	*361*	*12.3*	2,689	17.1	*513*	20.3
- Indoors	170	5.8	1,179	7.5	242	9.6
- Outdoors	191	6.5	1,511	9.6	[illegible]	10.8
Low income	*106*	*3.6*	505	3.2	*151*	6.0
- Indoors	102	3.5	489	3.1	145	5.7
- Outdoors	4	0.1	16	0.1	6	0.2
- **Light Industries**	819	28.0	8,074	51.4	777	30.8
- **Parks**	233	8.0	1,837	11.7	332	13.2
Irrigation	924	31.6	147	0.9	62	2.5
Electricity	247	8.4	1,590	10.1	351	13.9
Heavy Industries	237	8.1	873	5.6	337	13.3
Total	2,926	100	15,714	100	2,523	100

TABLE 6.3a: SUMMARY OF SCENARIO RESULTS

	Standard scenario	Scenario 1: Dry	Scenario 2: Wet	Scenario 3: High mortality
Assumptions				
- Tariff change	0%	35%	-20%	-40%
- Rainfall	Normal	Dry	Wet	Normal
- Population	Growth without Aids	Growth without AIDS	Growth without AIDS	High Mortality
Average water use				
- Total [million cubic metres]	3,408	2,926	3,583	3,423
- Deviation from standard		-14.1%	5.1%	0.4%
Economic value of water				
- Total [R millions]	R 17,777	R 15,714	R 18,941	R 17,819
- Deviation from standard		-11.6%	6.6%	0.2%
- Per cubic metre	R 5.22	R 5.37	R 5.29	R 5.21
- Deviation from standard		3.0%	1.2%	-0.2%
Bulk tariffs				
- Total [R millions]	R 2,223	R 2,523	R 2,219	R 1,647
- Deviation from standard		13.5%	-0.2%	-25.9%

TABLE 6.3b: SUMMARY OF SECTORAL DISTRIBUTIONS

Use Sectors	Standard scenario		Scenario 1: Dry		Scenario 2: Wet		Scenario 3: High mortality	
	Percentage distribution of water use sector							
Municipal use	**53.0**		**51.9**		**55.0**		**52.8**	
- Households	18.9		15.9		20.8		18.3	
High income	*13.7*		*12.3*		*14.7*		*13.2*	
- Indoors		5.5		5.8		5.5		4.6
- Outdoors		8.2		6.5		9.2		8.6
Low income	*5.2*		*3.6*		*6.0*		*5.1*	
- Indoors		4.9		3.5		5.7		4.9
- Outdoors		0.3		0.1		0.3		0.3
- Light Industries	24.1		28.0		22.9		24.0	
- Parks	10.0		8.0		11.3		10.5	
Irrigation	**32.8**		**31.6**		**31.5**		**33.0**	
Electricity	**7.2**		**8.4**		**6.9**		**7.2**	
Heavy Industries	**7.0**		**8.1**		**6.7**		**7.0**	
Total	100.0		100.0		100.0		100.0	

6.4 SCENARIO 2: WET CYCLE

Note once again that this scenario is done merely for illustrative purposes and may not be realistic in all respects. Also note that it is assumed that all other things stay the same.

In a wet cycle the reverse impact relative to that of a dry cycle can be expected. There will be a surplus supply of water, which will lead to lower tariffs, with the effect that the demand for water will increase. Important to note is that certain sectors which have a very inelastic demand are tariff insensitive and their demand for water will probably not grow. In Table 6.4 the results of scenario 2, which depicts a wet cycle, are shown (See also Table 6.3a and Table 6.3b).

The following aspects emerge:

- The most important aspect is that the total increase of water use is not what one might expect. Compared with the standard scenario, water use only increased by 5.1 %. This should be viewed in relation to a 20 % drop of the tariff. This gives a total elasticity of -0.26 compared to an elasticity of -0.40 in a dry cycle. This asymmetry is attributable to the assumption that irrigation will not be allowed to expand in the Vaal River system.
- The economic value of water increases marginally, relative to the standard scenario.
- In contrast with the insignificant change in water use, the impact of revenue received from the sale of water is significant. The authorities can expect to receive approximately R4 million (constant 1998 prices) less in revenue. This constitutes –0.2 % less than in the standard scenario. This result is consistent with microeconomic theory, which predicts that total revenue should fall when tariff declines along an inelastic demand curve.

The only sector which exhibited an increase (although small), was the household sector. This is once again, due to the high elasticities calculated in Chapter 4 (see Graphs 4.2-4.5)

TABLE 6.4: SCENARIO 2: WET CYCLE (Constant 1998 prices)

Assumptions						
- Tariff change	-20%					
- Rainfall	Wet					
- Population	Growth with moderate AIDS					
Economic value of water (Average over 2000 - 2014)						
- Total	R 18,941					
- Per cubic metre	R 5.29					
Use Sectors	**Average water use over 15 years (million m³)**	**Percentage distribution of water use sectors**	**Economic value of water in the Vaal River System [R millions]**		**Total bulk tariffs [R millions]**	
			Value	**Percentage**	**Value**	**Percentage**
Municipal use	1,969	55.0	16,291	86.0	1759	79.3
- **Households**	744	20.8	5,013	26.5	635	28.6
High income	*528*	*14.7*	*3,984*	21.0	*451*	20.3
- Indoors	197	5.5	1,364	7.2	168	7.6
- Outdoors	331	9.2	2,620	13.8	283	12.7
Low income	*216*	*6.0*	*1,029*	5.4	*185*	8.3
- Indoors	205	5.7	985	5.2	175	7.9
- Outdoors	11	0.3	45	0.2	10	0.4
- **Light Industries**	821	22.9	8,092	42.7	778	35.1
- **Parks**	405	11.3	3,186	16.8	346	15.6
Irrigation	1,128	31.5	179	0.9	46	2.1
Electricity	247	6.9	1,590	8.4	211	9.5
Heavy Industries	239	6.7	881	4.7	204	9.2
Total	3,583	100	18,941	100	2,219	100

6.5 SCENARIO 3: HIGH MORTALITY

Note once again that this scenario is done merely for illustrative purposes and may not be realistic in all respects. Also note that it is assumed that all other factors remain the same.

In this scenario it has been assumed that AIDS will have a serious effect on population growth. The average annual growth rate for the population over the period was taken as –1,2 % compared to a growth rate of 1,8 % in the standard scenario. The effect of this will be that there will be approximately 6 million people less in the catchment area at the end of the simulation period.

The impacts are as follows (See Tables 6.3 and 6.5):

- Under normal rainfall conditions the tariff could fall by as much as 40 % to equate demand and supply.

- The average use of water as well as the economic value of water will remain almost constant.

- A noteworthy impact in this scenario for the government in respect of future water development is that the revenue from bulk tariffs could drop as much as 25.9 %.
- As could be anticipated, a major impact of this will manifest in the use of water by households, which will drop by nearly 160 million m^3 if no adjustment is made to the tariff.

TABLE 6.5: SCENARIO 3: HIGH MORTALITY (Constant 1998 prices)

Assumptions	
- Tariff change	[illegible]

- Rainfall	Normal					
- Population	Growth with high mortality					
Economic value of water (Average over 2000 - 2014)						
- Total	R 17,819					
- Per cubic metre	R 5.21					
Use Sectors	Average water use over 15 years (million m^3)	Percentage distribution of water use sectors	Economic value of water in the Vaal River System [R millions]		Total bulk tariffs [R millions]	
			Value	Percentage	Value	Percentage
Municipal use	1,806	52.8	15,166	85.1	1339	81.3
- **Households**	627	18.3	4,252	23.9	357	21.7
High income	*451*	*13.2*	*3,413*	19.2	*257*	15.6
- Indoors	158	4.6	1,097	6.2	90	5.5
- Outdoors	293	8.6	2,317	13.0	167	10.1
Low income	*176*	*5.1*	*838*	**4.7**	*109*	**6.1**
- Indoors	166	4.9	800	4.5	95	5.8
- Outdoors	10	0.3	38	0.2	6	0.3
- **Light Industries**	821	24.0	8,097	45.4	779	47.3
- **Parks**	358	10.5	2,817	15.8	204	12.4
Irrigation	1,130	33.0	180	1.0	31	1.9
Electricity	247	7.2	1,590	8.9	141	8.5
Heavy Industries	239	7.0	883	5.0	136	8.3
Total	3,423	100	17,819	100	1,647	100

6.6 CONCLUSIONS

In this section various scenarios regarding supply and demand possibilities have been investigated. Although the exact level of these impacts could be questioned, the figures are probably in the correct ball park and the general direction of the results is in accordance with theory and expectations. The model is very general in nature and can be applied to answer various questions regarding water policy. The purpose of the scenarios is merely to give an indication of the types of analyses that could be explored by the model, and hopefully to encourage other researchers to make use of it.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

The authors of this report are of the opinion that the objectives set in the terms of reference of this study, as listed in chapter 1 of this report, have been met reasonably successfully. A physical water balance was derived in Chapter 3; demand schedules were determined in Chapter 4; Chapter 5 quantified the value of water resources and compared this with full economic costs; and a number of scenarios were explored in Chapter 6. A large amount of new information has been made available in the course of the study. In particular, a very significant contribution has been made to the development of natural resource accounts in South Africa. However, it must be emphasized that the expectations with which the project team began the study met with some disappointment. In many cases, the first-choice data that the team had expected to be available was of such poor quality that alternative methods of addressing the objectives had to be found. It is important to emphasize that the model developed in this study was constrained in this way by poor data. This has two consequences.

Firstly, it is not possible to verify the accuracy of the model's results against the 'real world', so that accuracy must be judged in terms of the quality of the data on which the model is based. In the light of what has just been said about that quality, it must be expected that the model will contain a degree of inaccuracy.

Secondly, this study has to some extent anticipated the process of data acquisition and analysis that water managers may be required to apply in practice in South Africa in future. These managers will thus also be confronted with the issue of poor data quality. To address this issue will require them to have access to improved data. In connection with the water use side of the model, the main problem was to obtain data from local authorities. The following aspects were especially problematic:

- In all cases identifying the correct contact person was a major obstacle. Data is not stored centrally and various departments had to be contacted.
- Once a contact person was identified, in many cases this person did not have sufficient knowledge to abstract data from the recording system.
- In a number of cases, the contact person could also not interpret the data abstracted.
- Historical data was virtually unobtainable.
- Water use data (volume as well as value) was in some cases not available on a suburb basis. Only total use data per local authority was available.

In connection with the supply side; the main problems included the following:

  - Inflow data was quite readily available from BKS, but some gaps existed. As data could only be obtained by running their simulation model, apparently a time consuming and costly process, gaps were filled by applying appropriate statistical techniques.
  - Evaporation data was not available at all and had to be estimated.

The negative aspect of this is that it must be accepted that many databases in South Africa are currently in a state that does not support sophisticated economic analysis; more positively, this study has laid a foundation on which other studies of this nature can build, although it must be accepted that their results, like those of the present study, will be somewhat approximate in nature.

This report has been rewritten several times. Each time, some of the detail of the model has been sacrificed for the sake of increased readability. Inevitably, this has led to a document that is partly incomplete, and readers interested in further detail are requested to contact the project team directly.

The model that has been constructed in this study must be viewed as a "living" one. Its usefulness lies much more in the future use that will be made of it than in the history of its development that has been reported in this present document. This, then, is the first recommendation of this report: that use of the model should be encouraged. The other recommendation of the project team is that water authorities in South Africa should take stock of the data that they may require in future to do their jobs, in particular in the light of changing water management requirements. They need to ask whether the data they will need is being collected and maintained in an accessible format; if this is not the case, they need to take steps to remedy the situation. If they do not do so, they, like this project team, may face some unpleasant surprises.

In conclusion it should be noted that the following objectives of the study have been reached:

* Determining the water balance and prevailing competition for water resources in the catchment.

* Deriving demand schedules for water for important water use sectors, i.e. domestic, irrigation, forestry, mining, industrial, power generation and eco-system uses.

* Quantifying the value of water resources at current levels of water use.

* Comparing the economic value with full economic costs and current water tariffs.

* Exploring a variety of scenarios and estimates the changes in the value and tariff of water resources, when negotiated and lawful transfers of rights to available water resources take place within or between existing uses.

ANNEXURE 2.1

(Annexure to Chapter 2)

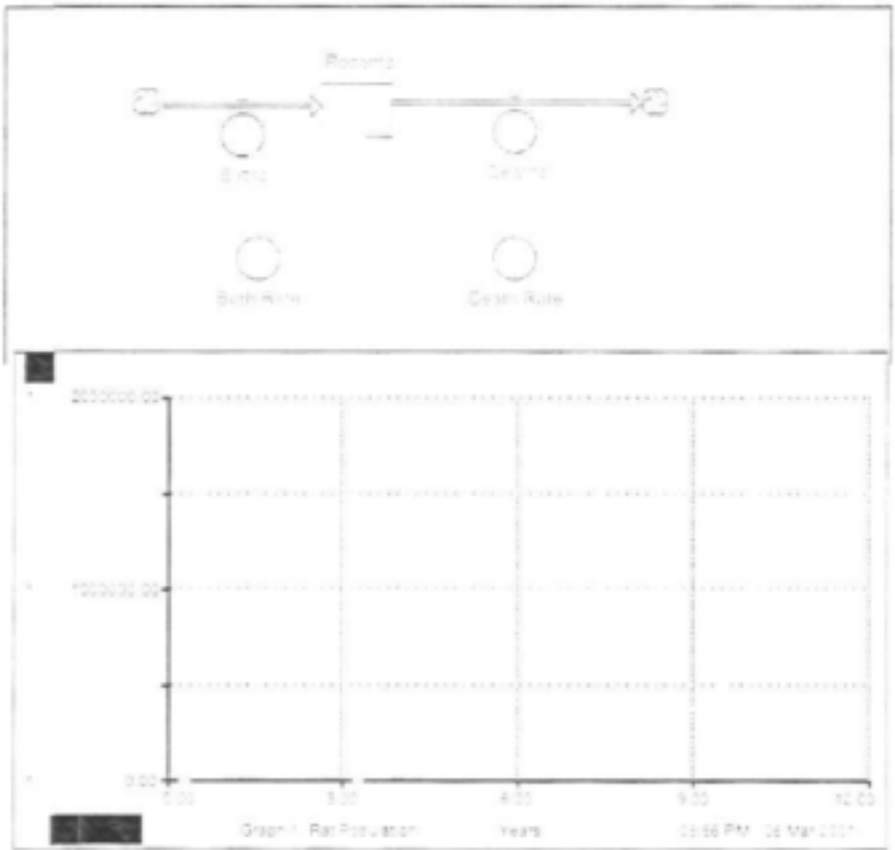
Example of a STELLA application

Some material in the Annexures is a repeat of that in the main text. This has been done in order to make the Annexures self-contained, obviating the need for the reader to page backwards and forwards.

Example of a STELLA application

The following simple example in Figure A.2.1.1 shows how the STELLA modelling system can be applied, by showing the growth of a population rodents.

FIGURE A.2.1.1 – GROWTH OF RODENT POPULATION



In the model above (Figure A.2.1.1), the stock was set to an initial number of 4000 rats. The growth rate was set at 1 rat per rat per annum and the death rate was set at 0.5 rats per rat per annum. The equation in the spigot for the entry flow is thus Rodents X Birth_Rate. At the exit, the flow is Rodents X Death_Rate. The graph simply depicts the increase in the stock of rats over a period of 12 years.

Annexure 2.2 contains a detailed description of elements of the Water Use Model.

For purposes of quick reference some tables are repeated here. The mathematical equations of the Use Model are depicted in Table A.2.2.1.

TABLE A.2.2.1: TOTAL GROSS USE OF WATER IN THE VAAL RIVER SUPPLY SYSTEM (MILLION M^3/ ANNUM)

(continued ....)

TABLE A.2.2.1 (CONTINUED)

KEY			
DTV	= TOTAL USE : UPPER VAAL	DIV	= TOTAL USE : IRRIGATION
DMTV	= TOTAL MUNICIPAL USE	DHIV	= TOTAL USE : HEAVY INDUSTRY
DMHV	= *Municipal Households : Total Use*	(CP)%V	= Percentage Change per Category
DHHIV	= Households : High Income Group	GGPV	= Gross Geographic Product per Category
DHHcV	= Households : High Income : Indoor Use		
DHHncV	= Households : High Income : Outdoor Use		
DHLIV	= Households : Low Income		
DHLcV	= Households : High Income : Indoor Use	AFFV	= Afforestation
		DOV	= Other (Wetlands)
DMGIV	= *Municipal Use : Parks*	GRWV	= Ground Water
DTB	= TOTAL USE : MIDDLE VAAL		
DMTB	= TOTAL MUNICIPAL USE	DEB	= TOTAL USE : ELECTRICITY
DHHIB	= Households : High Income Group	(CP)%B	= Percentage Change per Category
DHHcB	= Households : High Income : Indoor Use		
DHHncB	= Households : High Income : Outdoor Use	GGPB	= Gross Geographic Product per Category
DHLIB	= Households : Low Income	HECTB	= Hectares under Irrigation
DHLcB	= Households : High Income : Indoor Use		
DHLncB	= Households : High Income : Outdoor Use	AFFB	= Afforestation
		DOB	= Other (Wetlands)
DMLIB	= *Municipal Use : Light industry*		
DMGIB	= *Municipal Use : Parks*	GRWVB	= Ground Water
DMT	= TOTAL MUNICIPAL USE	DE	= TOTAL USE : ELECTRICITY
DMH	= *Municipal Households : Total use*	DHI	= TOTAL USE : HEAVY INDUSTRY
DHHI	= Households : High Income Group	(CP)%	= Percentage Change per Category
DHHnc	= Households : High Income : Outdoor Use	GGP	= Gross Geographic Product per Category
DHLI	= Households : Low Income	HECT	= Hectares under Irrigation
DHLc	= Households : High Income : Indoor Use		
		DO	= Other (Wetlands)
DMLI	= *Municipal Use: Light Industry*		

The equation describing each user category, can be explained as follows:

Total water use per category =
[average water use per unit + change in water use due to a tariff change] x total no of units

- Mathematically, this can be expressed as follows:

$D = [a - b(\Delta T)] \times C$

Where

D	=	Total use for a category
a	=	Average use per user unit
b	=	Change in unit use due to a given tariff change
ΔT	=	Change in water tariff
C	=	Total number of user units (driver exogenous variable)

- For example in Table 2.4 the fifth mathematical equation:
Municipal use: Households: High Income: Indoor.

DHHcV = [40.7284 – 10.5894 (CP)%1V] POP1V

can be interpreted as follows (for key to variables see Table A.2.2.1):

Average use per capita	= 40.7284 m^3 annum
Change in water units used due to a given tariff change	= 10.5894 m^3 annum
Percentage tariff change	= CP%1V

Total number of persons = POP1V (Drives exogenous variable = Population size in this category).

- **Average use term**

The **average use** i.e. a in the equation above, expresses a unit use of water, which could be per capita, per Gross Geographic Product (GGP) or per Hectare depending on the equation that is described. The average terms represent the constant portions of these equations. Calculation of unit terms was based on use data for 1998 which were supplied by BKS and DWAF (Annexure 2.2, Table A.2.2.2).

- **Change in use term**

Since the focus here is on tariff as a determining factor, the variable part (change in use or b) of the **use per unit** equation was obtained by redefining the definition of a price/tariff elasticity (Annexure 2.2, Table A.2.2.3). In words, the following was done:

- In equation (1) Annexure 2.2, Table A2.2.3 the price/tariff elasticity of demand (left hand side variable) is equated to the **ratio** of the relative change in demand to the relative change in tariff.
- This equation is then adapted to solve for change in demand (i.e. it becomes the left hand side variable). Change in demand is therefore now expressed in terms of the price/tariff elasticity, original tariff and demand and change in price. The price/tariff elasticity times the original demand yields a constant, which is the coefficient part (b) of the change in use term. The variable part is then the percentage tariff change. These two terms enter the equation multiplicatively (b x ΔT).

The average (or unit use term) a, as defined above, is obtained by merely dividing original demand by its appropriate driver or exogenous variable.

Terms a and b are then entered into the mathematical equation as indicated in formula (2).

In the mathematical model, the unit use portion was calculated as described above. The detailed calculation of these terms for Municipal use (Upper Vaal) is given in Annexure 2.2, Table A.2.2.2. The elasticity portion was derived from underlying demand schedules which is discussed in Chapter 4.

In order to convert these unit use functions to total use, these functions were multiplied with their respective "drivers" (exogenous variables), namely population, GGP or hectares.

TABLE A.2.2.2: CALCULATION OF MUNICIPAL COEFFICIENTS (UPPER VAAL)

USE SECTOR	WATER USE (U) (million m^3/a)	%	%	%	Population (million) (estimate)	%	Use per capita (U/cap) m^3/a	Elasticity (e)	Coefficients
	[illegible]	2	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 Households	454.81	40							
High income 1	341.10		75	100	[illegible]	0.40	101.9209		
- Indoor	[illegible].44			40	[illegible]		40.7284	-0.26	+17.[illegible]
- Outdoor	[illegible].66			60	[illegible]		61.0925	-0.9[illegible]	-55.3142
Low income	113.70		25	100	5.63	0.60	20.2036		
- Indoor	10[illegible].02			95	[illegible]		19.2484	+1.12	-21.[illegible]
- Outdoor	5.6[illegible]			5	[illegible]		[illegible]	-1.52	-7.[illegible]
2 Industry (GGP)	432.06	38				*1	*2	function *3	
3 Parks	250.14	22			3.35		74.6687	-0.91	-67.0485
TOTAL	1,137.01	100	100						
Aug 02					*1 = GGP		*2 = [illegible] GGP [illegible]	*3 annexure [illegible]	

SOURCES AND NOTES								
	SUM TABLE A DWR [illegible] [illegible]	WDM VRSSA p. v [illegible]	FWD+RF p 9-4	WDM VRSSA p 9-4	WDM VRSSA [illegible] TR134 p 4.2 [illegible] DBSA - Macro [illegible]	TR 134 p 4.2 [illegible] RWB [illegible] [illegible]	[illegible] Wet [illegible] Dry [illegible] [illegible] Total [illegible]	
	DWR WDM - VRSSA FWD+RF DBSA	Overview of Water Resources Availability and Utilisation in S.A. Water Demand and Management in the Vaal River System Supply Area Future Water Demand & Return Flows Macroeconomic & other indicators						

TABLE A.2.2.3: DERIVING CHANGE IN USE TERM FROM PRICE/TARIFF ELASTICITY FORMULA

Elasticity formula:

$$\varepsilon = (\Delta D/D) / (\Delta P_1 / P_1) \text{ ....(1)}$$

$$= \Delta D / D) \times (P_1 / \Delta P_1)$$

$$= (\Delta D / \Delta P_1) \times (P_1 / D)$$

$$\Delta D = \{(\varepsilon.D) / P_1\} . \Delta P_1$$

$$= \{(\varepsilon.D) / P_1\} . (P_2 - P_1)$$

$$= (\varepsilon.D) . \{(P_2 - P_1) / P_1\} \times 100$$
$$= b (\Delta P \%)$$

Where: $(\varepsilon.D) = b$ and
$\{(P_2 - P_1) / P_1\} \times 100 = (\Delta P \%)$

VOLUME (PER UNIT)

Demand = Ave Dem + Δ Demand

$$= a + (\varepsilon.D)(\Delta P_1) \%$$

$$Y = a - b (\Delta P) \% \text{ .... (2)}$$

LEGEND:

ε	=	Price/tariff elasticity of demand
D	=	*Use*
ΔD	=	Change in Use
P	=	Tariff
ΔP	=	Change in Tariff
(ΔP)%	=	Percentage Change in Tariff

INDIVIDUAL USE EQUATIONS

A: MUNICIPAL (DOMESTIC) USE

- ***Households***

The equations for consumptive and non-consumptive use for high and low incomes are behavioural equations. The explanatory variable in all cases is percentage tariff change. Tariff is assumed to be a proxy for price.

The constant terms were expressed as per capita use i.e. consumptive/non-consumptive use divided by population. These equations are therefore **population** driven. The assumptions regarding population over time, are discussed under exogenous variables below. In order to obtain total consumptive and non-consumptive water use these unit functions were multiplied by their respective populations.

The coefficient of the explanatory variable, percentage tariff change, was obtained by multiplying the per capita use with an appropriate constant price tariff elasticity (see Chapter 4). High and low income use are expressed as identities and are obtained respectively by adding consumptive and non-consumptive use. Total household use which is also an identity, is calculated as the sum of high and low income use.

- ***Light Industry***

The same general principles were applied here as well. The unit use term in this case, however, is expressed in terms of gross geographic products (GGP) units, or m^3/GGP per annum. This equation is therefore GGP driven. For GGP over time, see discussion of exogenous variables below. The coefficient of percentage tariff change was once again obtained as the product of the unit demand and a price tariff elasticity. In this case it should be noted that this elasticity is not a constant, but is entered as a non-linear curve. (See Chapter 4). To obtain total use by Light Industry, the unit function was multiplied by its GGP.

- *Parks*

The same basic principles were applied here as well and this equation is also population driven. It was assumed that the high income population, as used for consumptive use purposes, could approximate the population for this component. If the unit function is multiplied by this population, total use by Parks is obtained. Population over time is discussed under exogenous variables and it was assumed that the Municipal Use : High Income : Outdoor elasticity could be applied here.

B: IRRIGATION USE

This water use component is hectare driven and a constant average term of 10 000 m^3/hectare/year was applied. This amount was based on an expert opinion (Also see discussion under exogenous variables below).

The elasticity under consideration in this case, is also a non-linear function. For a detailed discussion see Section 4.2.2.

Total Irrigation use is obtained by multiplying hectares with the unit function.

C: ELECTRICITY USE

A function for electricity use is included for the Upper Vaal only. This function is driven by the GGP for electricity (calculation discussed below). Although its elasticity actually is a step function, it was approximated by a smoothed non-linear curve (See section 4.2.4 for discussion).

Total use is obtained if unit use is multiplied by its GGP.

D: HEAVY INDUSTRY USE

This component also only appears in the Middle Vaal model. A distinction is made between light industry use (under municipal use) and heavy industry. Light industry use was already discussed above and the same principles were applied in this instance.

The average term was therefore expressed in terms of GGP units (m^3/R million GGP/annum). A non-linear elasticity used for light industry, was also used in this case (See Section 4.2.3).

This Annexure contains a detailed discussion of the sources and calculation of the exogenous variables referred to in section 3.1.2.3.

Exogenous (or independent) variables are those variables which affect or determine the values of the endogenous (or dependent variables) in the model. In the document these variables are also referred to as the units in which the equations are expressed. For simulation purposes, the model requires historical as well as projected data.

There are four main exogenous variables in the model, namely:

- ***Percentage Tariff Change***

  No historical data is reported for this exogenous variable. This variable will only be used for simulation purposes to determine the effect of a tariff change on demand and to find the optimal tariff in the market where demand equals supply.

- ***Population***

  - *Historical:*

    Historical population figures per population group were obtained for the magisterial districts in Table 2.1 from Statistics South Africa (SSA) for 1996. Historic population figures per race group (1970-1995) for the RSA as published by the SSA were converted to indices with base year 1994. In order to obtain an index value for 1996, the 1994 - 1995 growth rate was applied to the 1995 index.

    It was assumed that these indices could serve as proxies for the study area and were applied to the 1996 population figures to obtain a historical series.

  - *Projections*

    Projections for each population group were made by applying the ABSA[11] projected growth rates for 1997-1998 to 1996 and throughout the forecasting period (i.e. 1999-2015). These population figures per population group were then aggregated to obtain totals for the study area.

    These totals were then split between High and Low income groups by means of percentages obtained from a Social Accounting Matrix (SAM) 1998 compiled by Conningarth Consultants (part of the present project team), since this is required by the mathematical model as discussed in Annexure A, Table 1. It should be noted that these projections do not make provision for Aids. This effect will be incorporated, however, when scenarios are done (See Chapter 6).

- ***Gross Geographical Product (GGP)***

---

11 Internal projections by ABSA.

Three GGP time series are required for the mathematical use model, namely:

- GGP for Municipal Use: Light Industry
- GGP for Electricity
- GGP for Heavy Industry
- Hectares

- **GGP for Municipal Use: Light Industry**

  It was assumed that the GGP for manufacturing could approximate this variable. GGP figures for manufacturing for the magisterial districts indicated in Table 2.1 were obtained from the Development Bank of South Africa (DBSA) Provincial Development Profiles for 1994 in constant 1990 prices. The unit of measurement being R million.

  Magisterial districts were sorted into their respective provinces and totals per province were obtained. These provincial totals were then converted by appropriate tariff inflators to represent 1998 figures at constant 1998 prices. These values were then aggregated to obtain a total for the study area for 1998.

  It was assumed that the production price index for manufacturing for South Africa (Historic values from SSA, forecasts Conningarth) could be used to approximate provincial GGP figures. This was therefore applied to the various provincial 1998 GGP values to obtain a series from 1980 - 2015. These provincial values were then added to obtain a total GGP for the study area per year.

- **GGP for Electricity**

  GGP figures for electricity per magisterial district are published in the DBSA: Provincial Profiles. Provincial totals within the study area were obtained by adding figures for the relevant magisterial districts together. In most cases values were published for 1994 at constant 1990 prices. These values were converted to 1998 figures at 1998 prices via appropriate price factors. It was once again assumed that the production price index for South Africa, (source: historic:

SSA, forecasts: Conningarth) could be used as a proxy for production in provinces. It was therefore applied to the 1998 values (at 1998 prices) for the respective provinces to generate sources from 1980-2015.

These provincial sources were once again aggregated in order to arrive at totals for the study area.

- **GGP for Heavy Industry**

It was assumed that GGP figures for Industrial Chemicals and Iron and Steel could serve as an approximation for the GGP of Heavy Industry. The basis for this calculation was formed by production price indices for Industrial Chemicals and Heavy industry from the same sources stated above.

In order to obtain a single index the following steps were followed:

- The percentage shares of industrial chemicals and iron and steel in GDP were obtained form ABSA[2)] sectoral aspects. These shares were applied to the 1998 GDP at current prices as published in the SARB Quarterly Bulletin (June 1999) in R-million.
- The production price indices for the respective sectors were applied to these values to obtain two series from 1980-2015.
- These two series were then added together to obtain a single series approximating Heavy Industry.

- ***Hectares***

As indicated before, it was assumed that the unit use of irrigation was 10 000 m^3 per annum. The hectares under irrigation per year were then calculated as demand for that year divided by 10 000 m^3.

Projected water use figures form BKS & DWAF were used to calculate projected values.

2) ABSA (2000): Sectoral Prospects for the South African Economy (1999-2006).

ANNEXURE 4.1

(Annexure to Chapter 4)

DERIVING DEMAND SCHEDULES/CURVES: HOUSEHOLDS

Some material in the Annexures is a repeat of that in the main text. This has been done in order to make the Annexures self-contained, obviating the need for the reader to page backwards and forwards.

1. DERIVING DEMAND SCHEDULES FOR HOUSEHOLDS

THEORETICAL FRAMEWORK

As mentioned in the main report, the main aim of this section of the study is to derive the domestic demand function to calculate price/tariff elasticities of demand for water[1]. Classical consumer theory predicts that a consumer's demand is a function of price (tariff) and income. More specifically, when considering water demand, this function has been expanded to include influencing factors such as:

- Climate (i.e. temperature, rainfall)
- Regional variation[2]
- Supply variance (i.e. supply uncertainty)
- 'some measure of real estate' (e.g. housing space) (Turnovsky, 1969)[3]
- Erven size
- Property value – used as a proxy for housing space (mentioned above).
- Socio-economic conditions
- The number of persons per household
- The percentage of persons per household under 18 years[4]
- Existence of own water supply e.g. boreholes.

In determining the 'price/tariff elasticities of demand for water' this study is essentially attempting to isolate the *tariff effect*. In order to be able to concentrate on this *tariff effect*, many of the above listed variables have been assumed constant across the entire sample[5]. This has been made possible by geographically restricting the study.

Restricting the study to the local authorities within the Vaal area at a specific point in time (1998) allows us to assume that the socio-economic profiles, weather patterns, hydrological factors, supply variability, and residential, commercial and industrial shares of total water use within each municipality are similar (Gibbons, 1986). Hence, of the variables listed above, only tariff, income, property value and erven-size have been included in the demand function. The demand function therefore takes the following form:

---

1) Estimating a demand function for water is extremely difficult because it is determined by many non-economic factors that cannot be included in the model (Turnovsky, 1969).

2) Foster & Beattie (1979) showed that water demand is more price elastic in areas where outdoor water use forms a larger fraction of total water use (e.g. arid areas).

3) Turnovsky, 1969. Ibid

4) One would expect per capita water use to be higher in areas with a large percentage of children (Turnovsky, 1969, p 352).

5) This technique has been used by a number of authors some of which include: Foster and Beattie (1979) and Döckel (1973).

$$\mathbf{Q} \quad = \quad \mathbf{b_0 - b_1T + b_2I + b_3PV + b_4E}$$

Where:

- Q = Quantity of water demanded per capita per year, in Kilolitres.
- T = Average tariff of water[69], given by total water demand divided by total amount billed, in Rands per Kilolitre. An average tariff is justified because even though a block-rate structure exists, the majority of households fall within the first consumption block, thus minimising the loss of accuracy by not using marginal tariffs[70].
- I = Average income, given as average annual per capita income in Rands.
- PV = Average property value, given as the average of the sum of the value of the stand plus any improvements, in Rands.
- E = Average erven size in m^2.

Theoretical expectations for the signs of each of these variables are:

- The intercept term (**b_0**) should be positive because water is essential for life, therefore consumers will always have positive consumption.
- The coefficient for water tariff (**b_1**) should be negative. Demand theory based on observation and empirical research, predicts that as the price of a commodity increases, the quantity that an individual will demand will decrease.
- The coefficients for property value (**b_3**) and erven size (**b_4**) should both be positive. Property value is used as a measure of the amount of real estate a consumer has. According to Turnovsky (1969, p 352), the more real estate a consumer has, the more water-using appliances they will have. Hence it can be expected that people with higher real estate values (property value) will have higher demands for water. The size of a consumer's property (erven) should give an indication of the size of the garden. One might therefore expect more water to be demanded on large properties as opposed to small properties.

- The income coefficient **b_2**, should also be positive, since it is expected that as income increases water demanded will also increase.

---

[69] See Gibbons (1986) page 14, who refers to Billings and Agthe's study in 1980, for a discussion on the advantages and disadvantages of using average price rather than marginal price. Hanke (1970), however, is also quoted in Gibbons (1986) to show that water demand is influenced by marginal tariffs.

[70] According to Gibbons (1986) most residential water demand studies have made this, or similar assumptions and have used average prices as well.

METHODOLOGY

Methods available to the researcher to quantify these demand equations are the following:

- **Contingent Valuation**

  Information is obtained by means of questionnaires. The first step is to establish a typical user profile. After this, the effect that a tariff increase would have on these consumption patterns is determined.

  A shortcoming of this method, is that outcomes are not actually observed, but are based on expectations.

  This method was used by Veck and Bill to determine the price/tariff elasticity of demand for water.

- **Time Series Analysis**

  Here tariff and demand data are compared over time (at least 14 observations) in order to determine a relationship between them.

  A shortcoming here is that the effect of other variables which also affect demand are excluded.

- **Cross Sectional Analysis**

  The reaction of different users to price/tariff changes at the same point in time is investigated. A relationship will be determined between consumption and tariff data for different municipalities. An advantage of this method is that many factors influencing water consumption, can be assumed to remain constant.

  For purposes of this study, this method was preferred.

DATA COLLECTION

Data were collected by means of questionnaires (See Table A.4.1.1). These questionnaires were sent to a sample of 23 (See Table A.4.1.2) local authorities in Gauteng. It was assumed that this sample could be used as a proxy for the study area. Results obtained from this sample could therefore be inferred to the total study area.

Questionnaires sent to these local authorities were explained to respondents by means of telephone conversations as well as personal visits in some cases.

The following basic information was required:

I. **Cross Sectional Data (For 1998)**

(i) The total **volume** of water consumed (kl);
(ii) The **monetary** value of the volume in (R);
(iii) An indication of the **population** involved;
(iv) Average **property value** (stand plus improvements) and
(v) Average **size of erven**.

It was requested that these data be reported i.t.o. five income groups, namely: Upper-, Upper-Middle-, Middle-, Lower-Middle and Lower income.

Income data for the various suburbs included in the sample, were obtained from statistics South Africa (SSA).

II. **Time Series Data (for at least 14 years)**

(i) Total **volume** of water consumption per year.
(ii) Total **monetary value** of the consumption in (i).

A total of 22 local authorities were contacted and 17 responded (See Table A.4.1.2). Of these, however, cross section information from only 13 was usable. It should be noted that, in terms of statistical confidence theory, a minimum sample size of 14 is required in order to derive significant statistical results. This sample size is therefore regarded as being somewhat small.

Only one of the local authorities contacted was in a position to supply time series data.

The possibility of a time series analysis was therefore ruled out.

It should also be noted that collecting data from these local authorities, was a very slow, costly and frustrating process. Faced simultaneously by financial crises, personnel restructuring and the need to become Y2K compliant, few of the local authorities were in a good position to provide the data sought; understandably, they also did not see the provision of data to researchers as their top priority.

TABLE A.4.1.1: LOCAL AUTHORITIES CONTACTED

DATA RECEIVED

	PQ Date	Municipality	Contact Person	Tel	Fax	First Contact	Last Follow up	Response (+)	Response (-)	Response None	Received	Comments	Visit
1		Pretoria	Carl Straub	(012) 308 8421	(012) 308 8111	26/01/99		X			27/04/99	-	26 Jan 99
2		Midrand	Kobus Oberholzer Stoffel Badenhorst	(011) 313 7757 (011) 313 7786	(011) 314 1568	24/03/99		X			26/03/99	-	25 Mch 99
3	X	Vereeniging				23/06/99		X			26/06/99	-	26 Jan 99
4		Westonaria	Henk Botha	(011) 753 1621 x852	(011) 753 4176	23/06/99		X			26/06/99	-	26 Jan 99
5		Delmas Tr C	Mr Steven Weber	(013) 665 5844	(013) 665 2013	19/06/99	30/07/99	X			03/08/99	-	
6		Highveld Ridge Tr C	Annette Brink	(017) 634 1100	(017) 634 1106	18/06/99	30/07/99	X			03/08/99	Might not be usable. Only Cons., Value, Tot Pop/town	
7		Heidelberg Tr C	Mev Hereldt	(0151) 3 1111	(0151) 3 111x2269		30/07/99	X			10/08/99		06 Aug 9h30
8	X	Springs Tr Council	Mr Robbie Hamilton	(011) 368 2256	(011) 812 1427	18/06/99	28/07/99	X			17/08/99		10 Aug 9h10
9	X	Boksburg City C (Alet)	Mr Sam Herman Mr Charles Kroon	(011) 899 4200 (011) 899 4201	(011) 917 13 18	24/05/99	02/08/99	X			22/08/99		
10	X	Krugersdorp TC	Marie Coetzee	(011) 951 2333	(011) 660 4043	25/05/99	15/10/99	X			21/10/99		
11	X	Kempton Park	Mr Willie v Vuuren Mr Ben Gerling Mr Coen Fatscher	(011) 921 2255 (011) 921 2152 (011) 921 2153	(011) 975 5814	24/06/99	07/12/99 17/02/00	X			04/04/00	Didn't receive fax - faxed again - forwarded to appropriate person. 7/12: on leave - 04/01	
12		Northern Metr LC (Randburg)	Hennie Snyman Derick Venter Mr Rehner Mr Elbere Hugo	(011) 787 9309	(011) 287 9365	22/06/99 [illegible]	04/08/99 18/02/00	X			[illegible] 14/03/00	29/07: Will fax results NOTHING DONE 19/02: Have started	26 Jan 99
13		Centurion TC	Mev Haupt Ledi Olivier	671 7640 671 7211	671 3502	17/05/99	08/04/00	X			10/04/00	Ready next month (Aug) - Not again - Haupt, Heymans left - fax Erwee	
14		Alberton Town C	Mr Johan Steyn	082 415 2095	(011) 861 2218	24/06/99 26/07/00		X			26/07/00	Not available.	26/07/00 12h00
15		Carletonville T L C	Ms Toeli Lesch	(018) 788 9572	(018) 788 962	27/07/00		X			2/8/00	No Middle Group Data Not on suburb basis	
16		Lethabong M T C (Edenvale)	Ms Viola Lebelse (Treasury)	(011) 456 0010 x139	(011) 452 0655	19/7/00		X			29/08/00	Consumption for four months only	26/07/00 12h00
17		Sasolburg T L C	Mr Derick Lawson	(016) 976 0029 (016) 976 2290		21/02/00	05/09/00				12/09/00	Don't have data on suburb basis - Only White - vs Black Town	
PROCESSING													
18		Western Vaal M L C (Vanderbijlpark)	Mr Martin Wheeler	(016) 950 5111	(016) 950 5207	24/02/00	5/9/00	X					
19	X	Brakpan TC	Ricco Reinecke Mr F van Wyk Mr Jannie Wagner	(011) 741 2030 (011) 741 2026 (011) 741 2010	(011) 741 2118	25/05/99	07/04/00			X		All attempts to contact van Wyk unsuccess 01/12: not right man - Jannie Wagner. 6/12 No reply	
20		Benoni Tr C	Mr Stan Smith	(011) 741 6005	(011) 741 6009	29/02/99	07/04/00	X				Forgot. Must check again in weeks time 01/02: Nothing - sell-message	
21	X	Germiston Town C	Mr Arnold	(011) 874 4045		25/05/99	05/08/99		X			No Population data. System frozen for research - 2000	
22	X	Nigel	Mr Jacobs	(011) 365 6580					X			Can't distinguish suburbs per income group	

TABLE A.4.1.2: QUESTIONNAIRE SENT TO LOCAL AUTHORITIES

DATA REQUIRED PER MUNICIPAL AREA (for 1998)

1. CROSS SECTIONAL DATA

The data in Table 1 below, are required for *DWELLING HOUSES (including DUETS)*

TABLE 1:

	(1)			(2)			(3)				(4)	(5)	(6)
SUBURB (Classified per Income Group)*	(1A) Total Consumption (kL) (1998)	OR	(1B) Average Monthly Consumption (kL) (1998)	(2A) Total Monthly Amount Billed (excluding VAT) (R) (1998)	OR	(2B) Average Monthly Amount Billed (excluding VAT) (R) (1998)	(3A) Number of Dwellings (Households)	(3B) Average Number of Residents per Dwelling	OR	(3C) Total Population	Average Property Valuation (Stands + improvements) (R)	Average size of erven (m^2)	Indication of usage of own* water sources (High, Med, Low)
Low Lower-Middle Middle Upper Middle Upper													
Total													
Calculation:	Sum of 12 months in financial yr (1/4/98 - 31/3/99)		(1A Total) / 12	(Jan + Feb+ ... +Nov+ Dec)		(2A Total) / 12							* Eg. Boreholes

* Data on **THREE** suburbs (Low, Medium and High) will be sufficient

2. TIME SERIES DATA: Required for the Total **Municipal Area** as well as for an **Established Suburb**
(Approximately 15 years)

2.1 Total Yearly Consumption (volume);
2.2 Total Value of Consumption in 2.1;
2.3 Total population (OR total number of Dwellings (Households) AND average number of persons per household

QUALITY OF DATA

On receiving some of the questionnaires it was obvious that much of the data were incorrect. Examples of where given values were incorrect include: some property values were given as 'stand' values only and excluded 'improvement' values; decimal places were often in the wrong place; monthly figures were given for total figures, etc. These values were corrected according to a priori and logical expectations and follow up conversations with respondents.

Disaggregation of data (based on the income groups) was not uniform. Some municipalities gave data based on only three of the five different income groups. It was therefore decided to aggregate the data into three income groups namely: Upper income, Middle income and Lower income. This was done using weighted averages based on the population in each income group.

ANALYSIS AND DISCUSSION

A: RESEARCH PROJECT

The analysis discussed below was done by Mr. Russell Wise as a Masters degree project, for the Department of Economics, University of Pretoria. Although most of it were used as such, some results were recalculated by Greengrowth Strategies cc. These deviations are indicated in the main report.

Once the data were collected and corrected, in a form that could be meaningfully used and analysed, the classical linear regression model based on Ordinary Least Squares (OLS) was used to determine the water demand function for the Vaal area. The computer software packages used were: Microsoft-EXCEL and EVIEWS. Many regressions were run using the four selected independent variables to determine a statistically significant model that would adequately describe the relationship between water consumption and each of the influencing factors.

The results obtained from these regressions are summarised and discussed in Table A.4.1.3.

The models listed in Table A.4.1.3 are suspected of having heteroscedasticity present in the error term. The variance of the residuals for each income group is suspected of being different. This is confirmed from the values given in Table A.4.1.3 which suggest that there is multicollinearity. A number of other variations for each model were tried but this problem could not be corrected.

The heteroscedasticity was corrected by dividing every observation, for each variable, by its standard error and re-estimating each equation. The results can be seen in Table A.4.1.4 It is clear from this table that the standard errors for each and every parameter have decreased, and the resulting t-values have improved substantially, suggesting that the corrections were successful. A reason for concern, however, is that some of the equations now have an R^2 value of 0.99 which suggests that there is multicollinearity. A number of other variations for each model were tried but this problem could not be corrected.

TABLE A.4.1.3: ESTIMATED EQUATIONS

	No. of Obser-vations	R^2	Re-sidual Var-iance
Equation A. Linear Regression Model Q = $b_0 + b_1T + b_2PV + b_3I$ Q = 18.82 + 3.32T + 0.0003PV + 5.01^{-5} se 20.13 8.53 7.21^{-05} 9.79^{-05} t 0.94 0.39 4.98 0.51 p 0.35 0.70 0.000 0.61	39 DW: 1.87	0.75	781.8
Equation 1. Linear Regression Model including dummy variables Q = $b_0 + b_1T + b_2PV + b_3I + b_4DU + b_5DM + b_6DU{*}T + b_7DM{*}T$ Q = 64.16 - 20.3T + 0.0003PV + 0.0007I - 253.3DU - 51DM + 58.1DUT + 21.1DMT se 23.70 10.71 7.13^{-5} 0.0005 92.79 57.72 18.01 19.31 t 2.71 -1.89 4.24 1.57 -2.73 -0.89 3.22 1.1 p 0.01 0.067 0.0001 0.13 0.010 0.378 0.003 0.282	39 DW: 1.88	0.83	594.8
Equation 2. Upper Income Group Q = $b_0 - b_1T + b_2PV + b_3I$ Q = -243.34 + 35.25T + 0.0003PV + 0.0011 se 115.05 19.47 0.0001 0.0005 t -2.115 1.81 3.057 1.75 p 0.063 0.104 0.013 0.114	13	0.77	866
Equation 3. Middle Income Group Q = $b_0 - b_1T + b_2PV + b_3I$ Q = 138.18 - 4.19T + 0.0002PV - 0.0017I se 96.77 19.87 0.0001 0.0015 t 1.427 -0.211 1.695 -1.105 p 0.187 0.837 0.124 0.297		0.40	741.3
Equation 4. Lower Income Group Q = $b_0 - b_1T + b_2PV + b_3I$ Q = 60.46 - 19.81T + 0.0003PV + 0.0021 se 20.63 7.58 0.0003 0.006 t 2.929 -2.614 0.9078 0.3482 p 0.017 0.028 0.3577 0.7357	13	0.45	201.9
Equation 5. Log-Log Model LogQ = $\log b_0 + b_1 LogT + b_2 LogI + b_3 LogPV$ LogQ = -1.349 - 0.565LogT + 0.218LogI + 0.337LogPV se 0.792 0.282 0.0699 0.121 t -1.814 -1.987 3.089 2.754 p 0.078 0.054 0.0039 0.0093	39	0.7	0.14

Note:
Unreliable data were received for Centurion and Heidelberg Upper Income groups. This has necessitated that average values, calculated from the rest of the Upper Income data, be substituted for these values.

TABLE A.4.1.4: ESTIMATED EQUATIONS USING TRANSFORMED DATA*

	No. of Observations	R^2	Residual Variance
Equation AT Linear Regression Model using transformed data Q = $b_0 1/sd + b_1 TT + b_2 TPV$ b_3 + $b_4 I$ Q = 23.0 + 1.50TT + 0.063PV + [illegible] Se 6.03 2.55 2.4[illegible] 3.37[illegible] t 3.82 0.59 14.73 1.98 p 0.0005 0.56 0.000 0.055	39	0.99	1.05
Equation 5T Log-Log Model using transformed data *LogQ = $\log b_0 1/sd + b_1 LogTT + b_2 LogTI + b_3 LogTPV$* *LogQ = 0.931 1/sd − 0.371 LogTT + 0.273LogTI + 0.148LogTPV* *se 0.262 0.274 0.0651 0.0536* *t 3.542 -1.353 4.20 2.349* *p 0.001 0.184 0.0002 0.0251*	39	0.99	0.03

*Transformed data:
These data have been transformed by dividing each variable by standard deviation. The standard deviations were calculated by squaring the residuals from the original estimations (using the original data) and square rooting these.

DISCUSSION OF THESE EQUATIONS

- **Equation A and Equation AT**

Equation A was first estimated including all the variables, with the idea of deleting those variables with t-values less than unity[16]. As can be seen, only Property value has a t-value greater than unity. Of the other variables, however, only 'Erven size' has been removed as it had a negative sign. The others have been kept for theoretical reasons. The same linear model using the transformed data (Equation AT, Table A.4.1.4) is a great deal better. Again, Erven size has been discarded because it had the incorrect sign. Tariff also has the incorrect sign but has been kept for theoretical reasons. The other variables have become statistically significant to the 99% level. This improvement confirms that heteroscedasticity existed in the original data. It also suggests that the three income groups should not be combined into a single equation as they have been in Equation A . To confirm this, an unrestricted model (Equation 1) was estimated by introducing two dummy variables to separate the Middle and Upper income groups from the Lower income group. The **Chow test** was then carried out to confirm whether 'income groups' are important in explaining water demand in the Vaal area (Gujurati, 1995). In other words, is it correct to run a combined equation (Equation A) or should separate equations be estimated for each of the three income groups (Equations 1,2,3,4)?

The following F-test was done:

H_0 : The three individual regressions for the income groups are the same i.e. there is structu
H_A : Structural stability is not present.

$$F = \frac{(RSS_r - RSS_{l,m,u})/k}{RSS_{l,m,u}/(\_n_{l,m,u} - 2k)}$$

Where: RSS_r = residual sum of squares of restricted equation.

$$= \frac{(27358.6 - 16281.2)/4}{16281.2/(39-8)}$$

$RSS_{l,m,u}$ = Sum of RSS for each income group

$$= 5.27$$

From the F-test (with 4 degrees of freedom in the numerator and 31 in the denominator), at the 95% confidence interval, the critical F-value = 2.67. Our F-statistic is greater than the critical F-value at this level.

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[16] This procedure was adopted by Turnovsky (1969, pp355).

therefore the Null hypothesis is rejected, and we do not reject the alternative hypothesis. Hence, Equation A will not be considered further and Equations 1,2,3 & 4 will be analysed and discussed.

- **Equation 1**

This equation was estimated using the same procedure as used to estimate Equation A. The 'Erven size' variable has been excluded because it's t-statistic was less than one and it's parameter sign was incorrect. The 'Income' variable has the correct sign, but is not statistically significant even to the 10% level. It has, however, been included for theoretical reasons.

The two dummy variables have been included to separate the three income groups. The upper income dummy variable is statistically significant to the 5% level indicating that it is statistically different from the lower income group. The middle income group, however, is not statistically different and only it's slope coefficient is above one. This dummy has been included purely to complete the separation of the groups. A detailed analysis of the *tariff effect* has been done for each income group below.

The R^2 value for this model is relatively large (considering cross-sectional data have been used) indicating that this model explains a large amount of the variation in water demand in the Vaal area.

Property value is the most significant of all the variables. This is not surprising considering that many authors (as mentioned above) have suggested that water demand is closely related to some measure of real estate, such as: the number of rooms per house, the size of the property, and the number of water using appliances within each house. Hence, 'Property value' might be considered as a good measure of real estate that helps explain water demand.

The low significance of the income variable might be because it is serially correlated with property value.

- **Equations 2,3 & 4**

Not a single variable for the **Middle income** group regression (Equation 3) is statistically significant to 5% - although, 'property value' is significant to the 10% level. 'Property value' is the only statistically significant variable (at the 5% level) in the **Upper income** regression (Equation 2) and 'tariff' is the only statistically significant variable (to the 5% level) in the **Lower income** regression (Equation 4).

A reason why *property value* is insignificant in the Lower income group and not in the other two groups is not quite clear. Turnovsky (1969), says that household water demand is *mostly* derived demand i.e. 'purchased in order to be used with water using appliances'. He goes on to say that the number of such appliances is clearly related to the amount of real estate enjoyed by the consumer (in this case property value). Because the property values in the lower income group are very low this might indicate that this group does not have many water using appliances, thus explaining the insignificance of this variable.

The *income* variable is statistically insignificant for all three groups but is included for theoretical reasons. The sign is positive indicating that as income increases one can expect the demand for water to increase. This is as the relevant theory predicts.

The *'tariff'* variable is only statistically significant for the Lower income group. The fact that the tariff parameter is insignificant for both the Middle and Upper income groups is surprising. Theoretically, tariff is expected to be a significant factor in determining a consumer's demand for water. Two reasons why this parameter is insignificant for the middle and upper income groups might be:

- The current tariff of water is unrealistically low (leading to small water bills relative to income and total household expenditure) therefore consumers do not consider the tariff of water when using water.

- Any changes in tariff are too small to cause these consumers to change their demand for water.

The converse of this would explain why tariff is statistically significant for the lower income group.

The *sign* for tariff is negative for the Lower and Middle income groups, as theory predicts. This indicates that a single unit increase in tariff will lead to a certain decrease in the quantity of water demanded (the amount of this decrease is indicated by the tariff parameter in each equation). The sign for the Upper income group, however, is positive which is contrary to all a priori expectations. The fact that the sign for tariff is positive for the upper income group does not necessarily mean that consumers consciously or purposefully increase demand as tariff

increase. Following from the reasoning above, this group is unaware of tariff increases, so their demand for water will increase to meet any increase in their wants and needs, irrespective of tariff. This discussion how water tariffs affect a consumer's demand for water is continued in the Elasticity section below.

The R^2 values for these three regressions are generally quite good. Even the R^2 values for the Lower and Middle income groups are satisfactory considering that cross sectional data have been used. The variance of the residuals is quite high especially for the middle and upper income groups. This might be because it is not easy to relate domestic water demand to pure economic factors (Turnovsky, 1969).

- **Equation 5**

Log-log models are very useful because the parameters estimates are elasticity measures. This method ensures that the arc elasticity is constant at every point on the demand curve. The same estimation procedure used for the above equations was used for this equation. Again 'erven size' was discarded because it had a negative sign and it's t-value was not greater than one. As can be seen from Table A.4.1.5, the other variables are statistically significant to 5% or better. An interpretation of the tariff parameter can be found in the Elasticity section. The other elasticity values are not discussed here.

The R^2 value is very good and the residual variance is extremely low, indicating that this model explains water demand in the Vaal area well.

2. ELASTICITIES

The focus of this study is to determine the effect that the tariff of water has on the demand for water. Elasticities are used to do this, as they are independent of units and are therefore more enlightening than regression coefficients. Only *price/tariff* elasticities of demand will be looked at in this section. The responsiveness of a consumer's demand for water to changes in income and property value, are suggested as possible areas of further research.

To calculate the price/tariff elasticity of demand for water, for each income group and the Vaal area as a whole, the following equation has been used:

$$E_d = \frac{dQ}{dT} * \frac{T}{Q}$$

Where:

$\frac{dQ}{dT}$ is the change in quantity demanded w.r.t. a unit change in the tariff.

T is the average tariff for each income group.

Q is the average quantity of water demanded by each group.

The results obtained from these elasticity calculations are summarised in Table A.4.1.3.

TABLE A.4.1.5

Elasticity Estimates at the Mean[17)]

Description of Group	Elasticity
Equation 1: Upper Income Group	**0.72**
Equation 2: Middle Income Group	**-0.15**
Equation 3: Lower Income Group	**-1.33**
Equation 5: Log-Log model of Combined Income Groups	**-0.57**

Lower Income Group

Elasticity = -1.33

This value indicates that the Lower income group in the Vaal area is water tariff ***elastic*** and that for a 1% increase in Tariff this group will decrease its water consumption by 1.33%. The fact that they decrease their consumption when tariff increases, is expected from traditional demand theory. But the decrease in consumption of more than 1% is not what one would expect when dealing with a good that is essential to life and that has no substitutes. The only explanation for this might be that relative to their income the water bill is so large that a slight increase in tariff has a relatively large effect on the amount of disposable income they have, and they therefore are forced to decrease their water consumption. Obviously this can only be done up to a point.

Middle Income Group

Elasticity = -0.15

This value indicates that the Middle income group's demand for water is water Tariff *inelastic* and that as Tariffs increase the quantity of water consumed decreases. So, a 1% increase in Tariff will lead to a 0.15% decrease in the

17)

	Cons/cap	Tariff	Erven size	Income/yr	Prop. Value
Ave Lower inc.	31.67133	2.128092	361.6923	3204.624	28817.02
Ave Middle inc.	84.04879	2.977692	913.3077	42758.43	128051.4
Ave Upper inc.	143.6014	2.963593	1284.077	177546.9	243138.2

amount of water consumed. This has been explained above and a comparison with the literature can be found below.

Upper Income Group

Elasticity = 0.72

An elasticity value of 0.72 means that this income group's consumption of water is Tariff *inelastic*. In other words a 1% change in tariff will result in a less than 1% change in the amount of water consumed. However, this elasticity value is positive which means that when tariff increases so will this group's consumption of water. This is contrary to what we would expect. An explanation for this might be the opposite of that given for the Lower income group. Relative to the income of this group of people the water bill is extremely small, therefore an increase in tariff will not force them to decrease consumption. This is expected to apply up to a certain point and then we would expect consumption to drop. To determine this point a study similar to that done by Veck and Bill (1999) can be done.

Combined Income groups

Equation 5: Elasticity = -0.57

An elasticity value of –0.57 indicates that the demand for water in the Vaal area is Tariff inelastic. In other words a 1% increase in Tariff will result in 0.57% decrease in water consumed. As water is essential for life and it has very few, if any, substitutes this is to be expected.

A comparison of these values with the literature is given in Table A.4.1.6.

TABLE A.4.1.6: SUMMARY TABLE OF SOME OF THE LITERATURE ON SHORT RUN PRICE/TARIFF ELASTICITY OF DEMAND FOR WATER

Researcher/s	Date	Type of Analysis & Location	Elasticity
INTERNATIONAL			
Howe and Linaweaver	1967	Cross-sectional U.S.A	Total: -0.40 Winter: -0.23 Summer: -0.70 to -1.57

Turnovsky	1969	Cross-sectional Massachusettes	-0.05 to -0.40
Wong	1972	Cross-sectional Illinois	-0.26 to -0.82
Billings and Agthe	1980	Time series Arizona	-0.39 (log), -0.63 (linear)
LOCAL			
Dockel	1973	Cross-sectional South Africa	White households:-0.69
Veck and Bill	1998	Contingency valuation, South Africa	-0.17

For further summaries and comparisons of short run Price elasticities for water usage see Gibbons (1986) and Veck & Bill (1999).

As can be seen from the table there is quite a range in Elasticity values (-0.05 to -1.57). The largest value indicates a very high elasticity for demand for water but cannot be compared with the high elasticity value calculated for the Lower income group in this study. The studies that have used variables similar to ours all have elasticity values between 0 and - 1 i.e. demand for water is usually price inelastic. Why all three income group elasticity values are so different from theoretical expectations and from the literature has already been suggested above. The unique situation in South Africa, where the Middle and Upper income groups have very high incomes compared with the lower income group, and the fact that water tariffs are so low, might explain the high price/tariff elasticity of demand for the lower income group and the very inelastic demand for the Upper and Middle income groups.

It is suggested, however, that because the results are so different from the theory and the literature, and because the situation in south Africa is so different from most other places in the world, that the data set be increased in order to rule out the possibility that the results are due to sampling inefficiencies.

Although elasticity estimates using cross-sectional data give an indication of the relationship between water consumption and other selected variables at a certain point in time, they can be used to estimate *long-run* behaviour if the situation prevailing during the year the cross-section data was collected, continues over the period one is wanting to estimate behaviour (Turnovsky, 1969). Hence, the elasticity values calculated in this study are relevant and useful to water resource planners and those responsible for formulating policy both **now** and in the **future**.

GREENGROWTH STRATEGIES CC

Greengrowth Strategies cc. has accepted the overall elasticity (-0,57, equation 5, pp 129-134) estimated by Mr Wise. It was decided, however, to also estimate the elasticities for the upper middle- and lower[11] income groups in the log-log form i.e. estimate a non-linear elasticity. These equations were therefore re-estimated, using the same specification as in equation 5.

The following elasticities resulted:

Upper middle income group:	-0,35
Lower income group:	-1,12

POLICY IMPLICATIONS AND SUGGESTIONS

It is believed that the data collected from these municipalities for this study are as good as one could probably get. It is conceded that more observation points would have improved the estimated equations and hence this is suggested as a possible avenue for further research. Also, in light of the difficulties experienced in collecting the data and the resulting quality of the data, if the data is going to be used in future for policy purposes, it is suggested that municipalities improve their record keeping and if necessary be given incentives by government to do so.

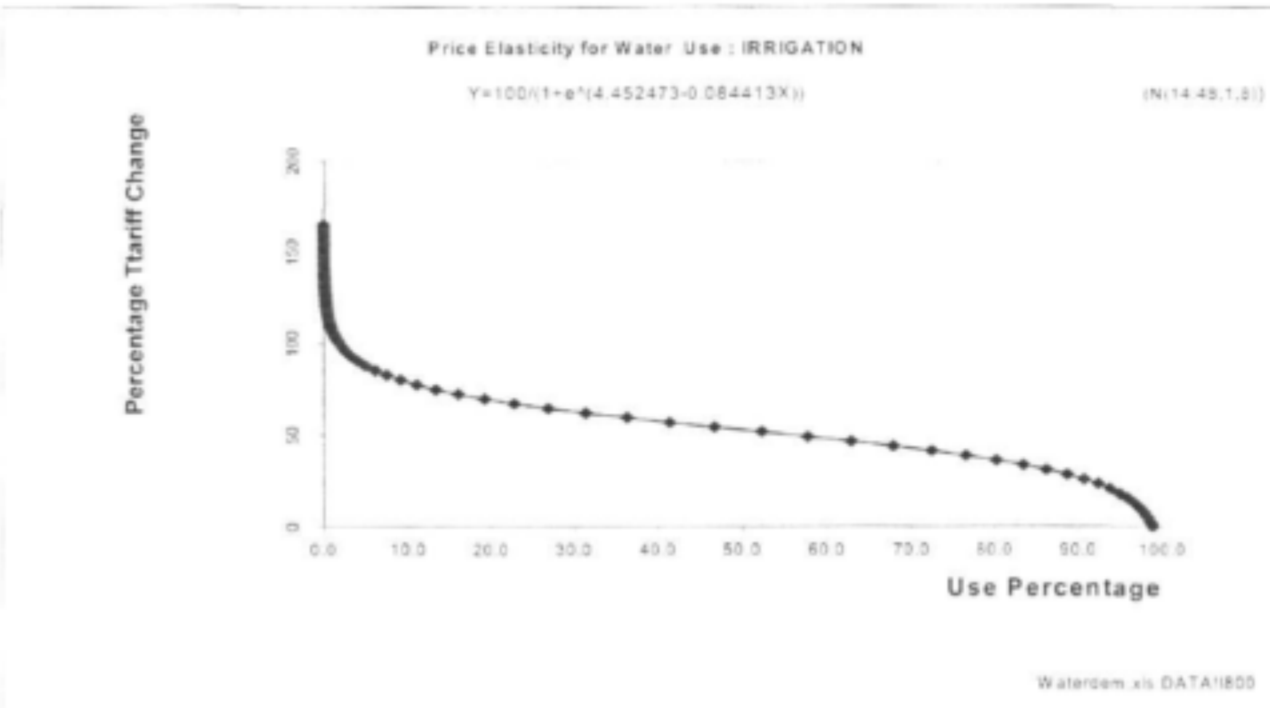
The clear difference in responsiveness to changes in tariff between the Lower income group and the other two, indicates that tariff control can be used as a policy instrument to control water demand. Even though the Middle and Upper income groups show small changes in their demand for water due to changes in water tariff, these groups are price tariff inelastic because the water bills and the changes in tariff that they face are so small that they are ignored. Hence, there is scope for substantial tariff increases to be imposed on these groups.

[11] Where Upper-Middle Income refers to the category of incomes above R26 900 per annum (1998 prices) and lower incomes below 26 900. These income levels were calculated, using the Social Accounting Matrix compiled by Conningarth Economists.

ELASTICITY OF IRRIGATION

The equation used to estimate the elasticity for irrigation, as well as a graph thereof, is presented below.

LOGDEM= C(1)+ C(2)*PRCH				
	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	4.4524	0.039	113.145	-
C(2)	(0.0844)	0.001	(107.995)	-
R-squared	0.9973	Mean dependent var		0.7447
Adjusted R-squared	0.9973	S.D. dependent var		2.1119
S.E. of regression	0.1105	Akaike info criterion		(1.5094)
Sum squared resid	0.3783	Schwarz criterion		(1.4187)
Log likelihood	26.9047	F-statistic		11,662.8100
Durbin-Watson stat	0.9172	Prob(F-statistic)		-



ANNEXURE 4.3

(Annexure to Chapter 4)

DERIVING A DEMAND SCHEDULE : HEAVY INDUSTRY

Estimation of Elasticity

Some material in the Annexures is a repeat of that in the main text. This has been done in order to make the Annexures self-contained, obviating the need for the reader to page backwards and forwards.

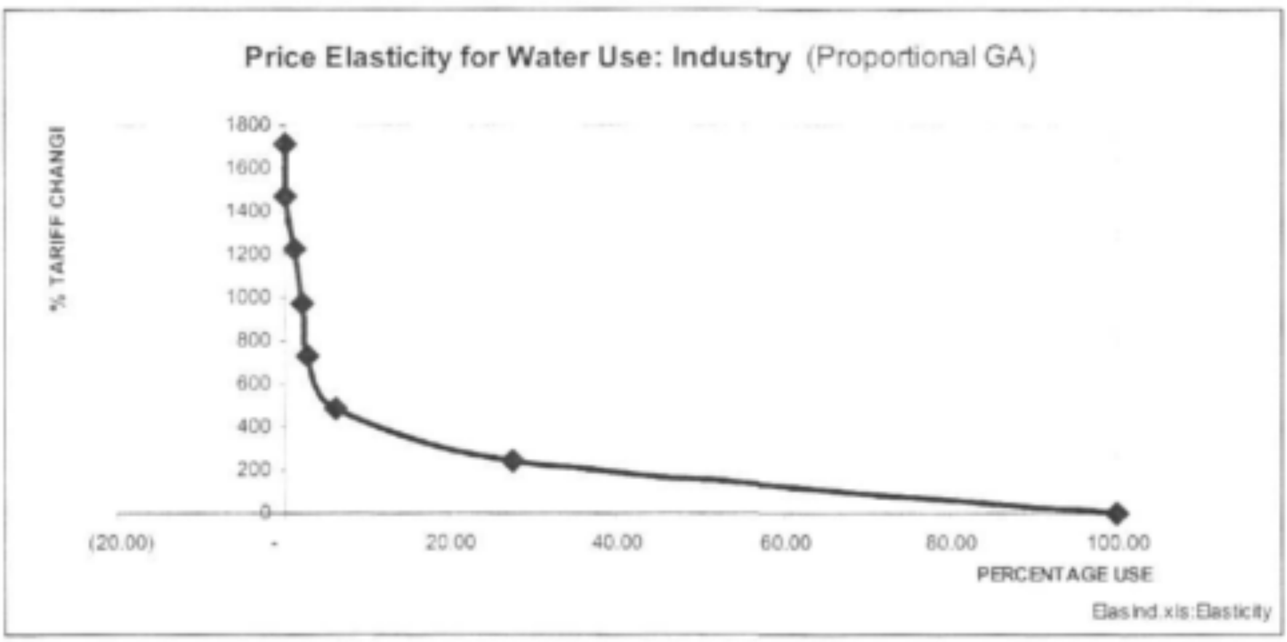
ELASTICITY FOR HEAVY INDUSTRY

The equation used to estimate as well as the corresponding graph: of the elasticity for this use sector, is shown below.

Included observations: 11 IndData.xls

LNDEM=C(1)+C(2)*PRPERCH

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	4.12624	1.759667	2.344899	0.0437
C(2)	-0.00159	0.000297	-5.345546	0.0005
R-squared	0.760478	Mean dependent var		-3.8236
Adjusted R-squared	0.733865	S.D. dependent var		6.04702
S.E. of regression	3.119555	Akaike info criterion		2.438347
Sum squared resid	87.58463	Schwarz criterion		2.510691
Log likelihood	-27.0192	F-statistic		28.57486
Durbin-Watson stat	1.258829	Prob(F-statistic)		0.000465



ANNEXURE 4.4

(Annexure to Chapter 4)

DERIVING A DEMAND SCHEDULE: HEAVY INDUSTRY

Assumptions and Methodology

Some material in the Annexures is a repeat of that in the main text. This has been done in order to make the Annexures self-contained, obviating the need for the reader to page backwards and forwards.

The methodology followed as well as the assumptions made in order to derive the elasticity function for heavy industry are discussed in detail in this section.

In the calculation of elasticity an input-output analysis coefficient approach was followed. Use was made of Technical Water Coefficients (the proportion of R1 that is spent on water in the production process in a given sector). The total manufacturing sector for South Africa (sectors 39 – 92) was considered for this purpose. Since the major South African industrial location is in the Gauteng area, it is regarded as a good proxy for the Vaal River system.

In order to determine the economic value of water to industry in the Vaal River system, the **location advantage rate**, i.e. the additional cost industry is willing to carry in order to be located in the Vaal River system, was used. Actual incentive cost required to induce relocation was applied for the Gauteng area.

A study by Urban-Econ[18] focussed on why industrialists do not want to relocate to other regions or stated otherwise, the advantages of being in the Gauteng metropolitan area from a cost point of view. The cost factors are identified in Table A.4.4.1 below.

TABLE A.4.4.1

AVERAGE COST PROFILE OF METROPOLITAN INDUSTRIES	
COST FACTOR	**% OF TOTAL COST**
Materials	32.7
Salaries	18.7
Inward transport cost	4.0
Outward transport cost	4.4
Rent	4.2
Interest paid	3.5
Electricity	4.1
Coal	3.5
Oil	3.6
Gas	3.5
Water	3.7
Outflow purification	3.5
Outside repairs	10.6
TOTAL	**100.0**

18) Source: Urban-Econ 1987: "Metropolitan Locational Analysis in a spatial economy with a decentralization interventionist policy". Unpublished.

The advantage to be located in the Gauteng Area relative to other areas in South Africa on average amounted to 5.9 % of total cost (Table A.4.4.2). This figure indicates the extra cost industries in the Gauteng area are prepared to pay for being located in the Vaal River system.

TABLE A.4.4.2

ADVANTAGE OF GAUTENG LOCATION		
ADVANTAGE LEVEL	% ADVANTAGE	WEIGHT (%)
High	11 - 21	10
Average	5 - 10	40
Low	1 - 4	50
Weighted average	5.85	100

Four cost items were identified as being sensitive to relocation i.e. inward and outward transport cost, rent and water. This amounts to 16.3 % of total cost. The total contribution of water to these four items amounts to 22.9 %. The local advantage for water is therefore 0.2 % (0.059 x 163 x 229). This is also equal to 0.037 x 0.059 (See Table A.4.4.1).

If it is assumed that industry is willing to add the total advantage to their water cost, the original technical coefficients can be adjusted to increase with full factor of 0.058 to obtain the maximum tariff increase coefficients that an industry would be willing to pay. It was assumed that this advantage would not only have an effect on water as an input in the production process, but would rather be distributed between the four sensitive items stated above. Therefore only a factor of 0.002 (0.2 %) was applied to the technical water coefficients to indicate the additional amount that an industry would be willing to spend on water. The percentage increase between the original and adjusted coefficients was then calculated. This percentage then represents the maximum tariff increase for water that an industry would be willing to accept. It should be noted that most of these percentages are extremely high because of the extremely low technical coefficients i.e. the percentage of water input is in many cases virtually negligible. See Table A.4.4.3.

A frequency distribution was constructed from these percentages and the volumes used by each sector. A non-linear curve was then fitted to the cumulative distribution to quantify the relationship between change in tariff and change in demand. This function was then used to represent the price tariff elasticity.

This non-linear elasticity will be used for the Light Industry (component of Domestic Use) as well as for Heavy Industry. Although it is technically possible to distinguish between light and heavy industries in the total manufacturing sector under consideration, and calculate separate elasticities for each, this was not done. The reason being, that it was already difficult to construct a meaningful frequency distribution from the total data set available due to the number of observations relative to the wide range of percentage changes. If the data is split up it would not be possible to construct meaningful frequency distributions from it.

TABLE A.4.4.3

THE VALUE OF WATER FOR INDUSTRY

GAUTENG ADVANTAGE (GA) = 5.85%

			Original Coefficient	METHOD 1 Add tot GA to WSS % Cost Increase	METHOD 2 Add prop of GA to WSS % Cost Increase 3.7%
Food & food processing	30111-30499	39	0.00077	7 659.13	282.65
Beverages	3051 - 3053	40	0.01039	562.55	20.83
Tobacco products	3080	41	0.00034	17 017.14	629.63
Textiles	3111 -3129	42	0.00269	2 171.32	80.34
Wearing apparel, except footwear	3130 -3150	43	0.00040	14 719.73	544.63
Tanneries and leather finishing	3161	44	0.00057	10 277.06	380.26
Leather products and leather substitutes	3162	45	0.00021	27 994.11	[illegible]
Footwear	3170	46	0.00027	21 493.[illegible]	795.27
Wood & wood products, except furniture	3210 -3223	47	0.00056	10 552.01	390.43
Furniture	3229	48	0.00021	28 137.93	1 040.92
Pulp, paper & paperboard	3231	49	0.00326	1 801.26	66.65
Paper containers	3232	50	0.00038	15 443.42	571.41
Other pulp, paper & paperboard articles	3239	51	0.00090	6 500.96	240.54
Printing & publishing	3241 -3260	52	0.00026	22 306.33	825.33
Industrial Chemicals	3310	53	0.00176	3 332.44	123.30
Fertilizers & pesticides	3321	54	0.00094	6 222.60	230.24
Synthetic resins, plastic materials & man-made fibres	3343	55	0.00067	8 773.75	324.63
Paints, varnishes & lacquers	3352	56	0.00449	1 303.56	48.23
Medicinal and pharmaceutical preparations	3353	57	0.00044	13 402.07	495.91
Soap, cleaning compounds, perfumes, cosmetics & toilet pr	3354	58	0.00039	14 954.38	553.46
Other chemical products	3359	59	0.00061	9 640.26	356.80
Petroleum refineries and products of petroleum/coal	3310	60	0.00165	3 540.20	130.99
Tyres & tubes	3371	61	0.00062	9 812.65	363.07
Other rubber products	3379	62	0.00156	3 749.40	138.73
Other plastic products	3380	63	0.00075	7 704.72	285.40
Pottery, china & earthware	3421 -3423	64	0.00033	17 396.29	660.15
Glass & glass products	3411	65	0.00306	1 918.54	70.99
Bricks, tiles, refractories, etc.	3426	66	0.00064	8 537.47	256.65
Cement	3424-3425	67	0.00024	23 972.06	886.97
Other non-metallic mineral products	3429	68	0.00104	5 645.80	208.89
Ferrochrome	3500	69	0.00107	5 447.90	201.57
Ferromanganese	3501	70	0.00079	7 413.60	274.30
Iron & Steel basic industries	3510	71	0.00112	5 202.54	192.51
Non-ferrous metal basic industries	3520	72	0.00052	11 311.41	418.52
Cutlery, handtools & general hardware	3533	73	0.00076	7 702.78	285.00
Furniture & fixtures primarily of metal	3910	74	0.00022	26 725.34	988.83
Structural metal products	3541	75	0.00079	7 380.79	273.16
Other fabricated metal products	35599	76	0.00112	5 208.27	192.71
Engines & turbines	3561	77	-		-
Agricultural machinery & equipment	3571	78	0.00037	15 772.74	583.59
Metal & woodworking machinery	3572	79	0.00014	42 731.15	1 581.27
Special industrial machinery & equipment	3579	80	0.00078	7 514.48	278.13
Office, computing & accounting machinery	3590	81	-		-
Other machinery & equipment	3569	82	0.00030	19 631.64	727.77
Electrical industrial machinery & apparatus	3610	83	0.00021	28 056.45	1 038.09
Radio, television & communication equipment and apparatu	3710	84	0.00016	38 304.01	1 417.25
Electrical appliances & housewares	3620 -3650	85	0.00061	9 567.00	353.98
Other electrical apparatus & supplies	3660	86	0.00033	17 947.08	664.08
Motor vehicles	3810	87	0.00018	33 156.87	1 224.27
Motor vehicle parts & accessories	3850	88	0.00084	6 976.47	258.13
Railway equipment	3860	89	0.00070	8 309.40	303.66
Other transport equipment	3879	90	0.00034	17 353.67	642.64
Jewellery & related articles	3921	91	0.00044	13 201.03	488.47
Other manufacturing industries	3920	92	0.00019	31 037.01	1 148.38

ANNEXURE 4.5

(Annexure to Chapter 4)

DERIVING A DEMAND SCHEDULE: ELECTRICITY

Estimation of Elasticity

Some material in the Annexures is a repeat of that in the main text. This has been done in order to make the Annexures self-contained, obviating the need for the reader to page backwards and forwards.

ELASTICITY FOR ELECTRICITY USE

The equation used to describe the elasticity of electricity use is described in Table A.4.5.1.

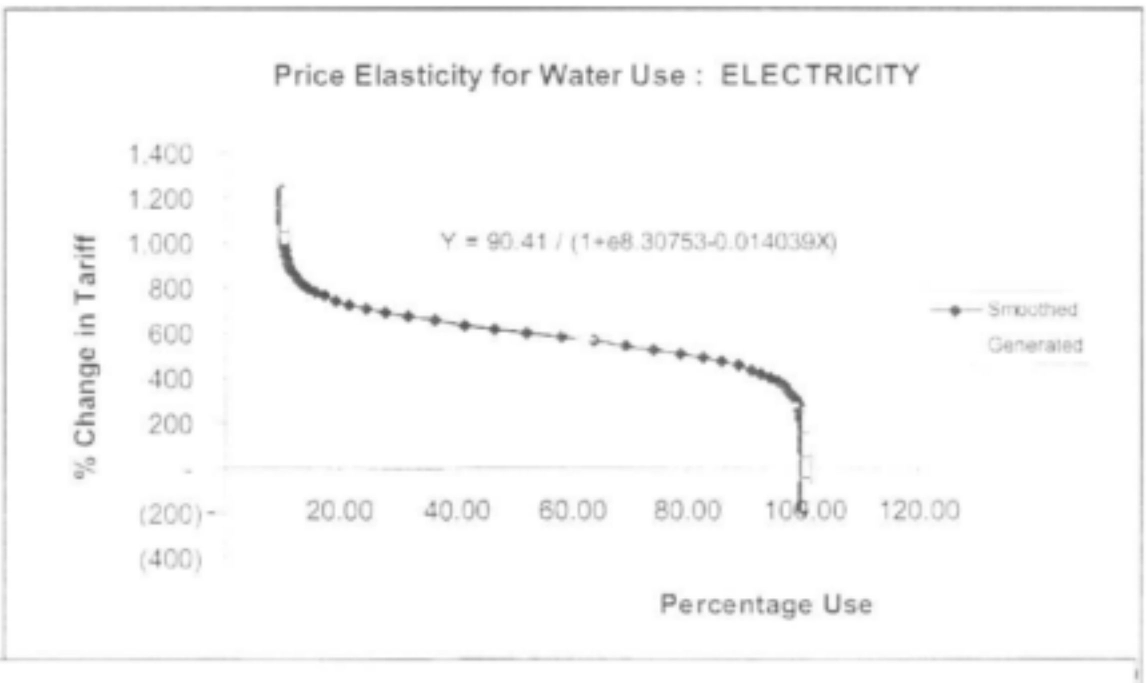
TABLE A.4.5.1

Regression output

Included observations: 69
LNUSECH=C(1)+C(2)*PERTARCH

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	8.307513	0.373847	22.2217	0
C(2)	-0.014039	0.000522	-26.90395	0

R-squared	0.915278	Mean dependent var	-0.3711
Adjusted R-squared	0.914014	S.D. dependent var	5.3527
S.E. of regression	1.5696	Akaike info criterion	0.9302
Sum squared resid	165.0641	Schwarz criterion	0.995
Log likelihood	-127.9986	F-statistic	723.82
Durbin-Watson stat	0.229443	Prob(F-statistic)	0



In this section, the data and methods relating to the delivery cost of raw water and the relevant tariffs are discussed.

1. Current status of RSA water pricing policies

South Africa is in the process of establishing a water pricing strategy.

On 12 November 1999 the South African Government published its raw water pricing strategy[10]. Although this strategy was not in operation in 1998, the base year of the present study, the basic concepts and information were used to establish, firstly, what water tariffs should have been at that time in the Vaal River and, secondly, as a proxy for water costs in the study area, given that tariffs and costs are required by the strategy to converge.

Objectives that shape the pricing strategy can be summarised as:

- Social Equity

  Redressing the imbalances of the past with respect to:

  * inequitable access to basic water services at affordable tariffs within municipal areas, by facilitating a subsidy on raw water cost where stepped tariffs are introduced
  * inequitable access to water for productive use purposes by subsidising tariffs for emerging farmers for a limited time period.

- Ecological Sustainability

  Pricing will take account of the cost of:

  * safeguarding the ecological reserve
  * the ecological management of a catchment
  * water quality protection
  * water conservation and use management

- Financial Sustainability

  Generating adequate revenue for funding the annual cost related to:

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10) DWAF, Raw Water Pricing Strategy, 1999, Pretoria.

* the management of water resources
* the operation and maintenance of existing schemes
* the rehabilitation of existing schemes
* the development of augmentation schemes

In the process of setting annual tariff increases to reach this objective, the constraints within various user sectors to adapt to tariff increases will be taken into account.

- <u>Economic Efficiency</u>

  * To promote the efficient allocation and beneficial use of water, water should be priced at its opportunity cost.
  * The Pricing Strategy provides for administrative as well as market-related measures to achieve this goal.

The nucleus of the policy is based on the principle of user charges. Cost allocations to user types (sectors) are as follows:

* Water resource management activity costs must be allocated to sectors in proportion to volumetric average annual sectoral use.
* Registered sectoral water use will take into account the assurance of supply from State and Water Use Authority (WUA) schemes.
* The Pricing Strategy determines that the following activity costs must not be allocated to the Forestry sector.
  - Dam safety control
  - The "Working for Water" (WFW) programme in South Africa

The setting of specific sectoral charges will take into account the following:

* Unit costs per sector will be determined for each Water Management Area (WMA) by dividing budgeted activity costs by the allocatable sectoral use.
* Unit charges in cents per m^3 for pricing purposes will take into account the subsidies granted i.t.o the Pricing Strategy.

  - The WFW unit cost for irrigation is subsidised by 90 %.
  - In under-utilised WMAs the charges are based on allocatable water and the under-recovery in revenue is subsidised by DWAF.

An example of the application of the above is set out in Table A.5.1.1.

TABLE A.5.1.1: EXAMPLE OF SETTING ANNUAL SECTORAL CHARGES FOR A WMA IN TERMS OF THE RAW WATER PRICING STRATEGY

Catchment Management Activity **Total Budget R10,0 x 10^6**	**SECTOR** **Total registered water use 1400 x 10^6m^3**			
	Municipal water use $100 \times 10^6m^3$	**Industrial water use $145 \times 10^6m^3$**	**Irrigation water use $680 \times 10^6m^3$**	**Forestry water use $475 \times 10^6m^3$**
Catchment Management Strategy Budget R1.5 x 10^6	$0,11^c/m^3$	$0,11^c/m^3$	$0,11^c/m^3$	$0,11^c/m^3$
Dam Safety Budget R0.2 x 10^6	$0,02^c/m^3$	$0,02^c/m^3$	$0,02^c/m^3$	Not allocated
Water Quality Management Budget R2.5 x 10^6	$0,18^c/m^3$	$0,18^c/m^3$	$0,18^c/m^3$	$0,18^c/m^3$
Water Utilisation Budget R2.5 x 10^6	$0,18^c/m^3$	$0,18^c/m^3$	$0,18^c/m^3$	$0,18^c/m^3$
Water Conservation • Use Management Budget R0.3 x 10^6 • Working for Water (WFW) Budget R3.0 x 10^6	$0,02^c/m^3$ $0,32^c/m^3$	$0,02^c/m^3$ $0,32^c/m^3$	$0,02^c/m^3$ $0,03^c/m^3$*	$0,02^c/m^3$ Not allocated
Sectoral charge	$0,83^c/m^3$	$0,83^c/m^3$	$0,54^c/m^3$	$0,49^c/m^3$
Revenue	R830 000	R1,204 000	R3,670 000	R2,328 000

* WFW subsidised by 90 % for Irrigation Sector.

In Table 1, total management costs are listed in the left hand column. These are then distributed across the volumes used by each sector listed in the top column of the table in order to desire the charge per cubic metre for each sector in the cells of the matrix. This provides the following total annual budget for the illustrative WMA:

Total expected revenue	R 8 032 000
Subsidy for WFW	<u>R 1 968 000</u>
Total budget	**R10 000 000**

In Table A.5.1.2 a detailed calculation is shown of the determination of the cost for a specific basin and the calculation of the tariff.

TABLE A.5.1.2: A SUMMARY OF CALCULATION OF THE WATER COSTS FOR A RIVER BASIN AND THE DETERMINATION OF THE TARIFF

Dam Unit Cost	Current 2000/01
Domestic and Industrial	
Return on asset cost c/m^3	6.02
Depreciation cost c/m^3	0.43
Betterments cost c/m^3	0.00
Operation & maintenance cost c/m^3	0.80
Functional support cost c/m^3	0.00
Infrastructure cost	**7.24**
Catchment management cost c/m^3	**0.03**
Working for water	0.02
Afforestation Abstraction cost c/m^3	0.01
Total unit cost c/m^3	7.27
Irrigation (full quota: 15000 ha in m 3)	
Betterment cost R/ha	0.00
Operation & maintenance cost R/ha	119.50
Functional support cost R/ha	0.00
Infrastructure cost	**119.50**
Catchment management cost	**1.58**
Working for water cost R/ha	0.30
Abstraction Afforestation cost	1.28
Sub total	121.08
10 % increase ito SAAU Agreement	12.11
Total unit cost R/ha	**133.19**
Total unit cost c/m^3	**0.0089**

REFERENCES

1. ABSA (2000): Sectoral Prospects for the South African Economy (1999-2006).

2. Asheim, G.B. 2000, Green National Accounting: why and how? In Environment and Development Economics, Vol. 5 Parts 1 &2.

3. Common, M., 1995, 'Sustainability and Policy. Limits to Economics', Cambridge University Press. p 121.

4. Conningarth Consultants, Evaluating the Impact of Selected Water Research Commission Projects – A Cost Benefit Analysis – A CBA Approach, 2000, unpublished.

4. Department of Water Affairs & Forestry, Raw Water Pricing Strategy, 1999, Pretoria.

5. Department of Water Affairs & Forestry, The Determination of the Economic Value of Water for the Vaal River System area, Project No. PC 000/00/10291,1991.

6. Department of Water Affairs and Forestry, October 1995, Vaal Augmentation Study: Water Demand in the VRSSA.

7. Döckel, J.A., 1973, "The Influence of the Price of Water on Certain Water Demand Categories, *Agrekom*, Vol. 12, No.3, pp 17-22.

8. Foster, H.S., Jr. and Beattie, B.R., 1979, 'Urban Residential Demand for Water in the United States', *Land Economics*, vol. 55 No. 1 pp 43-58.

9. Gibbons, D.C., 1986, 'The Economic Value of Water', *A Study from Resources for the Future, Washington DC, The Johns Hopkins University Press.*

10. Gildenhuys, J.S.H., 1999, Public Financial Management. J.C. van Schaik.

11. Lange, G. & Hassan, RM., (1999), Natural Resource Accounting as a Tool for Sustainable Macroeconomic Policy: Application in Southern Africa: IUCN Policy Brief.

12. Turnovsky, S.J., 1969, 'The Demand for Water: Some Empirical Evidence on Consumers' Response to a Commodity Uncertain in Supply', *Water Resources Research*, vol. 5, No. 2, pp 350-361.

13. United Nations, 1999, Integrated Environmental and Economic Accounting, Operational Manual.

14. Urban-Econ 1987. "Metropolitan location analysis in a spatial economy with a decentralization interventionist policy". Unpublished.

15. Veck, A., and Bill, M., 1999, The Water Research Commission Project K5/90. Price Elasticity of Demand for Water Survey no. 2 Report (CV experiment).

16. Viljoen, F.F., Symington, H.M., Botha, S.J. Verwantskap tussen waterbeperkings en Finansiële gevolge in die Vaalrivier watervoorsieningsgebied met spesiale verwysing na Besproeiingsboerderye in die Vaalharts gebied. WNK verslag 288/92. Bloemfontein. 1992.

17. UN document: "Calculation methods to assess the value of upstream water flows and storage as a function of downstream benefits".