RESPONDING TO A CITY'S WATER PRICES: THE CASE OF TSHWANE

By

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> “We need to ensure that there is development to meet the basic needs of our people, but that development should be mindful of our fragile resources.”
>
> Nelson Mandela

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- I give thanks for the privilege of stewardship on this beautiful planet.

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ABSTRACT

Water is considered one of the most essential of all natural resources and is currently classified globally as a scarce resource in terms of both quality and quantity. Current trends, recognise that water resources are an economic good and hence should be defined within a market structure and allocated according to some 'efficient' market price. However due to the nature of water as a social, financial, economic and environmental resource that is subject to spatial and temporal changes it is not easy to determine an appropriate set of prices. This move towards the efficient pricing of water resources is encompassed in the management approach focussed on demand management. The new Water Act for South Africa supports the move towards water demand management and hence economic pricing of water resources. Very little is however, known on the implications of pricing water resources in this way or on the responsiveness of consumers to these price changes. This dissertation focuses on the Tshwane municipality in South Africa. Using time-series and cross-sectional data, demand curves for water are estimated based on the pragmatic approach for the period 1995 to 2000. Price elasticities of demand for small agricultural holdings, household use at different income levels and industrial use are calculated. These results are then applied to consumer theory and the marginal values for water at these different levels are determined.

The elasticity results indicate that pricing can be used as an effective tool for water demand management in Tshwane. Agricultural small-holdings are more responsive than domestic users to price changes, and even more so in the long-run. Domestic water users tend to be relatively inelastic in their response to price changes, while industrial users prove to be the most responsive with a price elasticity of demand of –1.61, becoming –2.18 in the long-run.

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ACCRONYMS AND ABBREVIATIONS

Act	National Water Act No. 36 of 1998
CMA	Catchment Management Agency
CVM	Contingent Valuation Method
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
KL	Kilolitre of water (as part of the daily consumption)
LR	Long run
MRTS	Marginal Rate of Technical Substitution
NWRS	National Water Resources Strategy
RSA	Republic of South Africa
SR	Short run
SSA	Statistics South Africa
WC & DM	Water Conservation and Demand Management
WDM	Water demand management
WMA	Water Management Area
WTP	Willingness to pay
WUA	Water User Association

DEFINITIONS

Re-use	The re-use of water in any form, treated or untreated, often at a large scale, for example at a catchment or watershed level.
Recycling	The “process” by which water, that has already been used for some purpose, is collected, treated and then used again, either for the same purpose or for a different purpose.

CHAPTER 1 : SETTING

1.1 Background

Water is considered one of the most essential of all natural resources (Tietenberg, 1992). Current thinking recognises that water resources are an economic good and hence should be defined within a market structure and allocated according to some 'efficient' market price. However due to the nature of water as a social, financial, economic and environmental resource that is subject to spatial and temporal changes it is not easy to determine an appropriate set of prices (Kay et al., 1997; Winpenny, 1994; World Bank, 1993; McDonald and Kay, 1988).

Globally water is classified as a scarce resource in terms of quality where the physical supply is abundant and high levels of pollution and recycling limit access to clean water; and scarce in terms of quantity where climate changes and use patterns are rapidly dwindling established supply sources (Tietenberg, 1992; OECD, 1987; Kahn, 1998). Combined with the inevitable imbalance of water resources in terms of form, quality, location and the temporal characteristic of its nature (OECD, 1987), many countries are expected to reach levels of crisis within the next twenty to thirty years. Engelman and Leroy in Kay et al. (1997), state that 28 countries with an aggregate population of 338 million are currently recognised as water stressed (freshwater supplies of only 1,000 to 1,600 cubic meters per capita per year). Twenty of these have an annual supply of less than 1,000 cubic meters per capita per annum, classifying them as water scarce. Scarcity or shortage referred to here not only describes the limits of some variant condition of the hydrological cycle, but includes the boundaries reflected in economic terms by the gap between the quantity supplied and the quantity demanded of the resource, water (Darr et al, 1976). Barney, in Tietenberg, (1992) estimated that "by the year 2000, world-wide global water supplies would only be three and a half times the demand due to population growth".

1.2 The nature of water

Water is defined by Hassan (1997b) as having the following characteristics:

- It is a public good (by interpretation, not privately owned).
- The renewable supply is governed by the hydrological cycle and the long-run elasticity of water supply is relatively inelastic.

- It is essential to the existence of human life, as well as to the functioning of ecosystems and the perpetuation of biodiversity.
- Water has no substitutes.

Based on the classical theory of public goods and the definition proposed by Samuelson (1954 and 1955) this view implies non-exclusion and non-rivalry in the consumption of water resources, characteristics that are pertinent to developing water economies or situations where supply schemes are operated below their capacity constraints. These views on water as a resource for basic needs are however, challenged by Randall (1981) in his review of the definition of public goods and hence the characteristics of water resources. Accordingly, Randall (1981) recognises four axes of classification for economic goods based on the "possibility that the good may be provided by markets and the possibility that its provision may be pareto-efficient", they are: divisible and exclusive goods, divisible and non-exclusive goods, indivisible and exclusive goods, and indivisible and non-exclusive goods. Based on this work it is evident that water resources and the management thereof can result in rivalry and excludability with allocations falling short of pareto-efficient goals.

The primary source of fresh water comes from precipitation, with stocks held in the form of lakes, rivers, reservoirs and underground aquifers. Precipitation varies considerably within annual timeframes and between years. Constant flow patterns are not normally observed. Floods may follow droughts from one year to the next. Erratic climatic conditions further exacerbate the global unpredictability of precipitation. The spatial characteristics of water means that in some countries scarcity is not necessarily a national problem but may be severe in certain regions, compounded by the demand dependent nature of certain sectors over other sectors. Globally, agriculture is regarded as the largest user of water, followed by industry and households respectively. These observations are often even more skewed for developing countries that have invested a large part of their economies into agriculture (World Bank, 1993).

1.3 Approaches to water resources management

Historical approaches to water resources management have focussed on supply-side management. Demand needs were met through increasing the supply of water, through reservoir construction, infrastructure development, inter-basin transfers and transboundary schemes. These approaches are becoming increasingly expensive due to the costs of infrastructure, operation and maintenance costs, inaccessibility to exploitable water sources and the spatial distances that need to be covered. No charge was made to account for the opportunity cost or scarcity value of the resource itself. Consequently, water was regarded as almost a 'free good'.

Water demand management approaches provide a means by which user demands may be satisfied without resorting to costly and timely supply-side development. Two approaches to demand-side management are the use of market and non-market incentives to influence user behaviour. The most popular market incentive depends on pricing (water tariffs) followed by water markets, auctioning and pollution charges. Non-market incentives such as: restrictions, education and persuasion, and quotas and norms may also prove beneficial but have generally been evaluated in conjunction with pricing changes, as a result their direct impacts are often difficult to identify (Winpenny, 1994). Demand management aims to elicit desirable changes in the quantities of water demanded by consumers through intervention (both public and private), in an attempt to remove inefficiencies and inelastic supply gaps (Hassan, 1997b). The economist's role in determining the most efficient demand-supply solution will depend not only upon information about consumers incomes, tastes and preferences, the prices of substitutes and compliments, but most importantly on the behavioural response of the consumer to changes in water prices (Darr et al, 1976).

1.4 South Africa

An example of a country that is moving away from supply-side solutions towards demand management in order to cope with water scarcity problems is South Africa. It is situated at the southern most tip of the African continent and is bordered by four countries namely, Namibia, Botswana, Zimbabwe and Mozambique. It is regarded as the economic powerhouse of the South. The country has a total surface area of 1,2 million km^2 and is mapped by a number of perennial rivers, many of which are shared by its bordering countries, for example, the Orange River, shared by Namibia and Lesotho. Rivers are the main source of water in South Africa and approximately 77 percent of the population of 45,5 million have access to safe water (DBSA, 1998). Due to large income discrepancies the ability of large sectors of the population to cover the costs of service provision are limited. In spite of South Africa's extensive services infrastructure and technological efforts, it is becoming less feasible to continue with the development of supply-side approaches to extract exploitable water resources in order to address the water needs within the country, due to the escalating associated costs. Combined with the annual precipitation of only 500mm per annum and increasing demands, it is expected that current supplies will soon be surpassed by demand. As a result, demand management provides invaluable options for addressing existing inefficiencies and meeting new demands.

In response to the emerging demands on water resources, the Department of Water Affairs in South Africa has undergone a major reform in its water policy evidenced in the compilation of the New Water Act (Act 36, 1998). The new water act addresses issues of equity distribution, efficiency in water use and recognises a reserve allowance to meet primary and environmental water needs. It also discusses the importance of allocating a 'true value' to the nation's water resources. The South African government is determined to redefine water resources as national assets and to establish pricing mechanisms that ensure that efficiency goals are met in conjunction with equity and socio-political goals. One important aspect of this move towards resource pricing is the responsiveness (elasticities) of consumers/ users to these price changes. If users appear to be unresponsive to price changes then government needs to consider other policy measures in order to achieve the desired policy goals.

1.5 Problem statement

In spite of South Africa's extensive infrastructural developments and technological efforts, the development of currently exploitable water resources is no longer feasible due to the high associated costs. In addition, concerns around the ability of existing supplies to meet future water demand are growing. Combined with a semi-arid to arid climate and an annual precipitation of about 500mm per capita, per annum, South Africa is recognised as being a country approaching levels of severe water scarcity. Simultaneously, the Department of Water Affairs and Forestry has undertaken to supply the first block of water for basic needs free of charge. Water demand management, due to the constraints of scarcity and increasing demand is being widely adopted in order to address water management. An inclusive component of this strategy is the economic pricing of water and the new National Water Act for South Africa encompasses this very principle. However, pricing only serves to influence demand patterns where consumers are responsive to price. By understanding the behavioural responses of users to the prices of water, government may be better able to allocate and manage water resources efficiently, furthermore a clearer understanding of the value of water will facilitate allocation of the resource in its 'best alternative use'. This study aims to debate the effectiveness of demand management for the Tshwane Municipality thereby providing policy recommendations on water pricing management options for the city's water sector.

1.6 Hypothesis

In light of the current emphasis on demand management in South Africa, it is expected that correct pricing may be used as a mechanism for altering demand patterns for water resources within the country. This thesis therefore hypothesises that pricing is an effective tool for water demand management. In order to test this hypothesis the following sub-hypotheses will be tested:

- Residential water demand is price inelastic with the locus of the estimate of elasticity near to that found for arid or semi-arid regions, between 0 and –1.
- Agricultural smallholdings water demand is price elastic with a locus of the estimate of price elasticity between –1 and -∞.
- Industrial water demand is more price elastic with a locus of the estimate of price elasticity closer to –1.

1.7 Objectives and motivation of the study

In response to the policy questions posed by water managers across the country, this study will focus on one specific municipality in order to account for homogeneity in the explanatory variables and aim to achieve the following objectives:

- Collect time-series data on prices and quantities of water used in the Pretoria municipality.
- Derive demand curves for water for the following sub-sectors within the municipality:
- Domestic demand (for middle and low income users)
- Agricultural small- holdings
- Industrial demand
- Estimate the short and long run price elasticities of demand for water in the Pretoria municipality.
- Record and analyse the results.
- Determine a value for water for the municipality based on Gibbons (1986) approach.
- Provide policy recommendations on the results.

1.8 Research methodology

In order to address the policy problem of whether supply pricing mechanisms can be used to encourage a reduction in the quantity of water demand for various user categories, it is necessary to know the level of demand from which elasticities may be determined based on the functional form of the estimated equation.

For the purposes of this study time-series data for different cross-sections of the Tshwane Municipality will be used. This secondary data on prices and quantities is available for the five years (1995 – 2000) disaggregated monthly. Data prior to this time is not available due to the unfortunate incidence of fire destroying previous records. The data is already categorised according to certain user groups based on the reporting structure of the municipality. Further data on influencing characteristics such as rainfall and temperature was obtained from the South African Weather Bureau on a monthly basis.

A model for residential water demand, based on utility theory shown below, will be estimated for the various user categories using ordinary least squares analysis. From the results, elasticities will be obtained in order to inform the role of pricing in water resources.

The generic model will be as follows:

$$\begin{aligned} &\textit{quantity demanded water} = \\ &f\left(\begin{array}{r} \textit{average price}, \textit{marginal price}, \textit{number of users}, \textit{rainfall}, \text{max}\textit{imum temperature}, \\ \textit{household income}, \textit{population}, \textit{seasons} \end{array}\right) \end{aligned}$$

with specifications for three levels of users, namely domestic use, agricultural small-holding use and industrial use as follows:

$$Q_{wd} = f\left(P_{wd}, Other\right) \qquad (1\text{-}1)$$

$$Q_{wa} = f\left(P_{wa}, Other\right) \qquad (1\text{-}2)$$

$$Q_{wi} = f\left(P_{wi}, Other\right) \qquad (1\text{-}3)$$

Where,

Q_w = the quantity of water per capita per annum (cubic meters)

P_{wd} = the price of water (per cubic meter) in Pretoria for domestic use

P_{wa} = the price of water (per cubic meter) for agricultural small holdings

P_{wi} = the price of water (per cubic meter) for industries with Pretoria

from which the derivative of a log function will yield the price elasticity's of demand for water as follows:

$$\frac{\partial Q}{\partial P} < 0, \quad for\ each\ sector \qquad (1\text{-}4)$$

1.9 Outline of the study

This study will be set out as follows: Chapter 2 provides a background to water availability and use within South Africa, while chapter 3 reviews the literature on various approaches to water demand management. Chapter 4 builds the link between water economics and pricing and reviews the role of demand curves and elasticities. Chapter 5 is a continuation of the literature review with specific focus on the methodology of estimating demand functions and the choice of methodology for this study. Chapter 6 provides a description of the data variables, summarises the estimations and provides an analysis of the results. Finally, chapter 7 gives recommendations for policy based on these results.

CHAPTER 2 : WATER AVAILABILITY AND USE IN SOUTH AFRICA UNDER PAST AND CURRENT MANAGEMENT AND ALLOCATION REGIMES

2.1 Introduction

The Republic of South Africa is situated at the southern most tip of the African continent, falling roughly between 16 to 32 degrees longitude and 22 to 35 degrees latitude. It is bordered by four countries namely, Namibia, Botswana, Zimbabwe and Mozambique and is regarded as the economic powerhouse of the south. It covers a total surface area of 1,2 million square kilometres, making it the third largest country in the SADC region (DBSA, 1998). Much of its surface area is classified as semi-arid or arid. Summer temperatures fall between 18°C and 40°C, while winter temperatures range between minus 4°C and 15°C.

Despite having a coastal zone enriched with good rainfall, the majority of the country is classified as water-scarce. The average annual rainfall is 500mm compared to the global average of 800mm, and is further limited by its variable and unpredictable nature (McKenzie et al, 1999). South Africa's poor endowment of ground water combined with high evaporation rates and the direct demands of a population of 45,5 million people currently growing at an average annual rate of 2,3 percent (DBSA, 1998), place further pressures on its scarce surface water resources.

In light of the above-mentioned natural constraints to water supply, this chapter aims to place the need for water demand management in South Africa into context by providing an overview of water availability and use and the policy regimes that govern water resources within the country.

The first section of this chapter outlines the water sector by identifying the various sources of supply and the management structures under which they fall. The second section provides a sectoral analysis of water use and the consequential implications for water scarcity. Section three provides an overview of the water policies both historical and current governing water resources within South Africa and section four identifies the area selected for the purposes of this study, giving a general overview of its characteristics.

2.2 The water sector

The South African water sector has been likened to a "large plumbing system" evidenced by the intricate systems of inter-basin transfer schemes and varied sources of supply (Haasbroek and Harris, 1998). It is also managed at numerous levels through hierarchical governing bodies. The NWA (DWAF, 1998) has made water a national asset that one may have the right to use for a stipulated period. In line with this thinking and the large number of people without access to basic water needs within the country, the first 6 litres per day will be supplied free of charge. The countries water resources are diverse and spatially extensive, resulting in numerous water related opportunity costs to the country. Hence, the need for different users of large-scale consumption levels, to apply for the right to extract and use the water.

2.2.1 Water supply sources

"Five types of water sources are recognised, namely, surface run-off from rainfall, ground water, unconventional water sources, reuse of effluent returned to public streams, and water imports from other countries" (DWAF, 1986). Surface run-off is the predominant source of water in South Africa with a total volume estimated at 54,500 million cubic meters per annum (DWAF, 1986). Groundwater is distributed throughout the country in a series of aquifer systems. It provides on average an economically utilisable volume of about 5,400 million cubic meters per annum. Water supplies reclaimed through effluent recycling are expected to meet the demands of regions with rapidly expanding urban and industrial growth, where this water meets the required quality standards. However, this approach is only expected to become a reality for domestic purposes when it is no longer economical or practicable to draw from or develop conventional sources. As mentioned in chapter 1, the developments of a number of unconventional sources are being investigated. Desalination is being used to improve brackish ground water or purifying recycled water but is still too costly an approach in improving large quantities of seawater. Rainfall augmentation is regarded as one of the more feasible supply options for the interior although research results have been inconclusive. International developments on the use of icebergs are being monitored but are not regarded as possibilities at present. Moisture is being obtained from the atmosphere on a very small scale in suitable regions and water harvesting is being considered as an option, as well, in order to meet the increasing demands. Finally, water imports from neighbouring states have proven to be very successful, one such example is the Lesotho Highlands water project, although such schemes are dependent on the political stability of the region (DWAF, 1986; Hassan, 1997).

2.2.1.1 Surface water

Perennial rivers cover over a quarter of South Africa's surface, mainly in the southern, south-western and eastern plateau parts of the country. Non-perennial rivers occur over a further quarter of the country, while episodic and random flows occur in the remaining rivers. Strong seasonal fluctuations combined with irregular flow patterns characterise the perennial rivers making flow predictions difficult and increasing water stress during certain times of the year and within certain regions (DWAF, 1986).

2.2.1.2 Groundwater

Ground water occurs in secondary aquifers over 80 percent of the area of South Africa at depths of up to 50 meters. Most of these aquifers are limited in the volume of water that can be extracted from them and as a result are mainly used on farms or in rural areas to provide small quantities of water for domestic use, stock-watering or small-scale irrigation. However, groundwater stored in dolomite strata 200m to 1,900m thick, may be mined in large volumes capable of servicing urban and irrigation demands on a larger scale. The occurrence of sinkholes does however remain a threat to extensive dolomite based aquifer mining. The occurrence of primary aquifers within the country is limited. Depending on the rate of recharge of these aquifers and the rate of extraction of water, they may be classified as either renewable or non-renewable water resources and need to be managed with caution. Furthermore, water abstracted form these sources is often not suitable for consumption and requires investment into purification technologies (DWAF, 1986).

2.2.1.3 Water transfer schemes

South Africa is epitomised by an intricate inter-dependent network of inter basin transfers. Due to the limited supply options of many catchments pressured by rapid economic and population growth, these schemes have proven to be invaluable in meeting the demand requirements in many areas, facilitating industrial growth and relieving drought stricken areas. The water transfer schemes transfer water from one river catchment to another via a network of dams, pumping stations, pipelines, canals, tunnels, and weirs. The major water schemes in South Africa are:

The Komati Scheme: This scheme transfers water from the Komati Basin to the Olifants River Catchment area. An average of 131 million m^3 water is transferred through this scheme in order to supplement the Olifants River and the water needs of the Eskom power stations.

The Usutu Scheme: This scheme was built after the Komati Scheme, and transferred water from the Usutu River in order to supply the Camden, Kriel and Matla power stations. A total of a 103 million m^3 water is transferred annually by this scheme.

The Usutu-Vaal Scheme: This scheme was built in order to provide water to the Sasol oil-from-coal plant as well as to the Matla and Duhva power stations. A total of 100 milliom m^3 per annum may be pumped into the Vaal River system through this scheme.

The Emergency scheme: The Komati, Usutu and Usutu-Vaal Schemes were designed in order to provide for water security in the presence of drought. As 80 percent of South Africa's power generation is dependant on these schemes to varying degrees, they were constructed in an inter-linked fashion so that water could be drawn from any of the three schemes during times of need.

The Orange-Sundays-Great Fish Water Transfer Scheme: This scheme draws water from the orange river in the central parts of the country and channels it through a series of tunnels and canals over 100km in length to the Sundays river in the eastern part of the country, thereby also supplying the Great Fish with water for irrigation agriculture.

The Tugela-Vaal Scheme: Pumps water over the Drakensberg Mountain range (escarpment) at a height of 550 meters above the source into the upper Vaal catchment. This supplies the urban and industrial heart of the country (the Gauteng Province) with water. Construction commenced in 1969 and was subsequently updated. This scheme allows for a saving of about 455 million m^3 of water annually in the Vaal River system.

The Lesotho-Highlands Water Scheme: Construction on the Lesotho Highlands Water Scheme commenced in 1998, aiming to transfers headwaters from the Orange River in Lesotho to the Vaal River System in South Africa via a system of tunnels. This scheme is an example of what can be achieved through transboundary co-operation and agreement. It is currently recognised as the largest inter-basin transfer scheme in Southern Africa (Haasbroek and Harris, 1998). The Lesotho Highlands Water project consists of four phases, the first of which is expected to be entirely completed by the year 2004 at a cost of between R15 to R20 billion. Phase 1B is expected to increase dependable supplies of water to South Africa from a current 17m^3/s to 29m^3/s. There is still deliberation as to the continuation of the next three phases in light of the enormous costs involved (Poggiolini, 2001). The complete scheme is expected to transfer 2,200 million m^3 of water per annum. Table 2-1 shows the water delivery capacity of the scheme at its different stages.

Table 2-1: Lesotho Highlands Water Scheme – water delivery capacity

Water delivery	1A	1B	II	III	IV
Increment (m^3/s)	18,2	1,9	9,5	25,4	9,6
Total (m^3/s)	18,2	20,1	29,6	55,0	64,6
Year of commissioning	1996	2002	2004	2017	2020

Source: Lesotho Highlands Water Scheme, 1991

Many smaller schemes have also been constructed within South Africa, particularly after 1994, in the country's efforts to connect a multitude of new users to fresh water supplies (DWAF, 1986b).

These supply-side solutions to meeting increasing user demands lie at the core of the historical approaches to water management within South Africa. This has, however changed in light of tighter budget constraints, increasing costs, limited exploitable sources and expanding rural connections. The new water policies currently aim to use demand-side management strategies to combat the threat of water scarcity (see section 2.2.4).

2.2.2 Water management areas in South Africa

There is a move within South Africa towards decentralising the management of water resources. One of the key components towards this end is the establishment of catchment management agencies. The decentralised hierarchical management structure in which catchment management agencies fall is shown in figure 2-1.

The country is divided into eleven provinces governed by independent provincial bodies. The National Water Resources Strategy prescribes a framework within which water will be managed at catchment levels falling into defined water management areas. As a result, the country is also split into nineteen water management areas (DWAF, 2000). Figure 2-2 shows the water management areas of South Africa, they are marked by the red borders and the names of the major rivers within these catchments are shown in the white blocks. The black borders outline the nine provinces and the black dots indicate the situation of the major towns. Tshwane is indicated on the map under the former name, Pretoria and falls into the northern section of the Gauteng Province and the Upper Vaal Catchment Management Area.

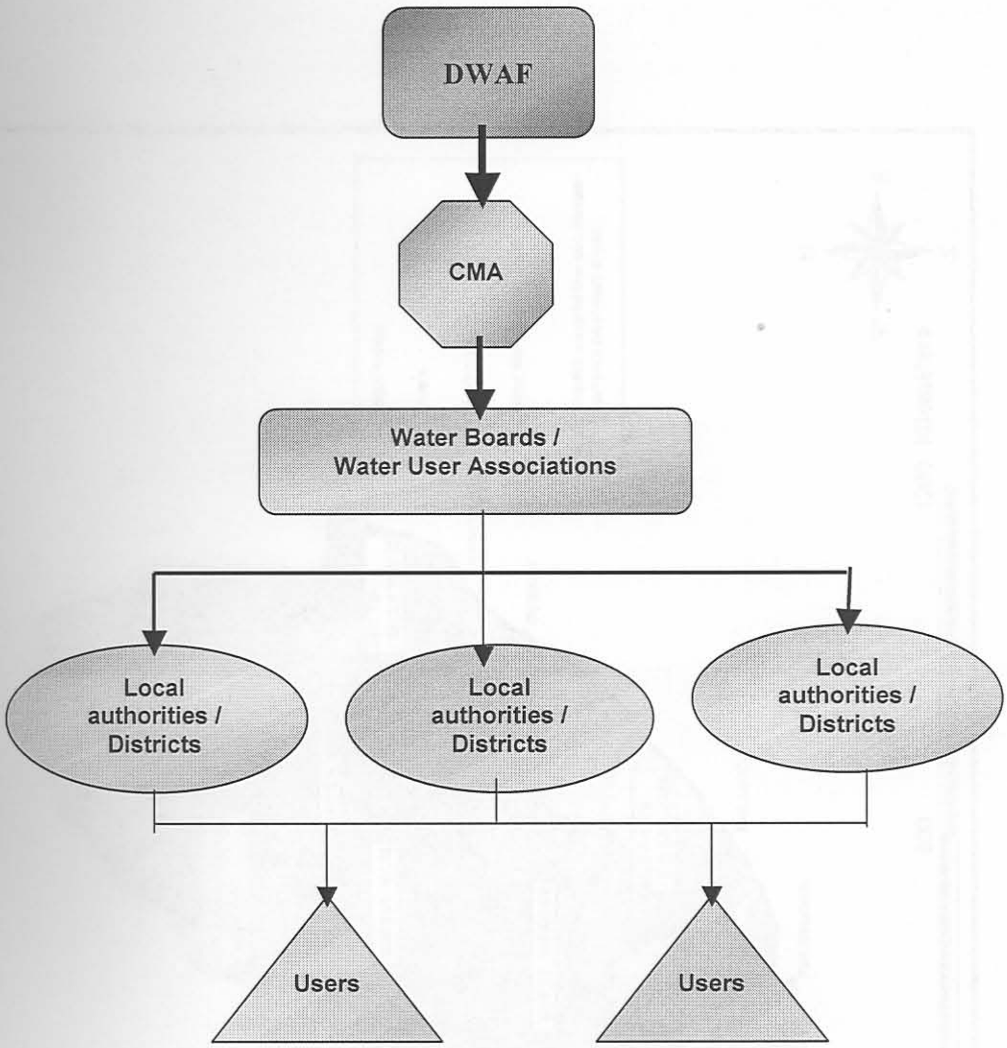

Figure 2-1: Water supply hierarchy for South Africa

Source: Own creation

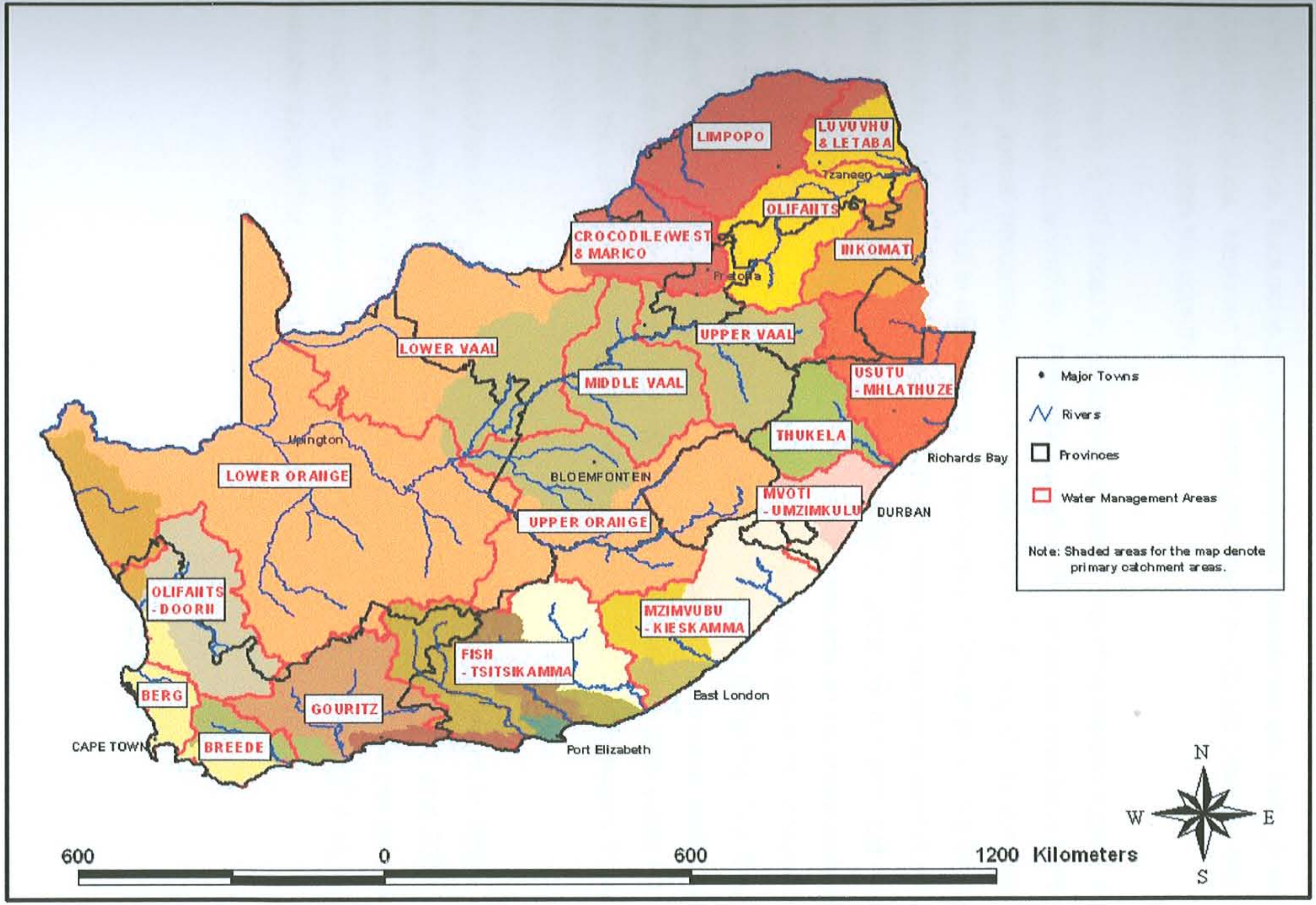

Figure 2-2: Water Management Areas of the RSA

Source: CSIR, 2000

2.2.3 Water demand and supply imbalances

Regarded as one of the most valuable resources to the functioning of the South African economy, water scarcity may prove to be the "limiting factor to economic growth and social development," while inducing water-related health problems and environmental degradation (Haasbroek and Harris, 1998). Water is renewable to some extent in the short-run but long-run supply is generally recognised as being fixed. It also varies greatly within South Africa, fluctuating across geographical boundaries and through temporal and seasonal demands. However, these characteristics alone do not preclude the situation of water scarcity within the country.

Water scarcity is influenced by a number of factors including meteorological, topographic and demographic constraints. Precipitation within the countries' interior is highly sporadic. The mean annual precipitation (MAP) is about 500 mm, slightly above half the world average of 860 mm, but in many areas of the country is further pressured by high rates of evaporation. Diverse climatic conditions prevail, ranging from winter rainfall and dry windy summers in the western parts to summer rainfall (thunderstorms) and cold dry winters in the north-eastern Highveld. The interior is arid to semi-arid and is characterised by erratic annual rainfall matched by extremely high temperatures, while the coastal belt has a relatively high rainfall with subtropical conditions extending along the East Coast. Due to the diversity in topographical, climatic, and evaporation constraints, water availability is distributed extremely unevenly. Only 20 per cent of the surface area yields 60 per cent of the mean annual runoff (MAR), estimated to be 50150 x 10^6 cubic meters (Haasbroek and Harris, 1998).

The implications of water scarcity within South Africa are evident in figure 2-3, which depicts the supply of water against the demand for water in 1996 and 2030. Supply is estimated to remain the same at a level of 33,290 10^6 cubic meters per annum. Demand is expected to increase from 20,045 (10^6m^3 / a) to 30,415 (10^6m^3 / a), reducing the available surplus from 13,245 to 2,875 (10^6m^3 / a).

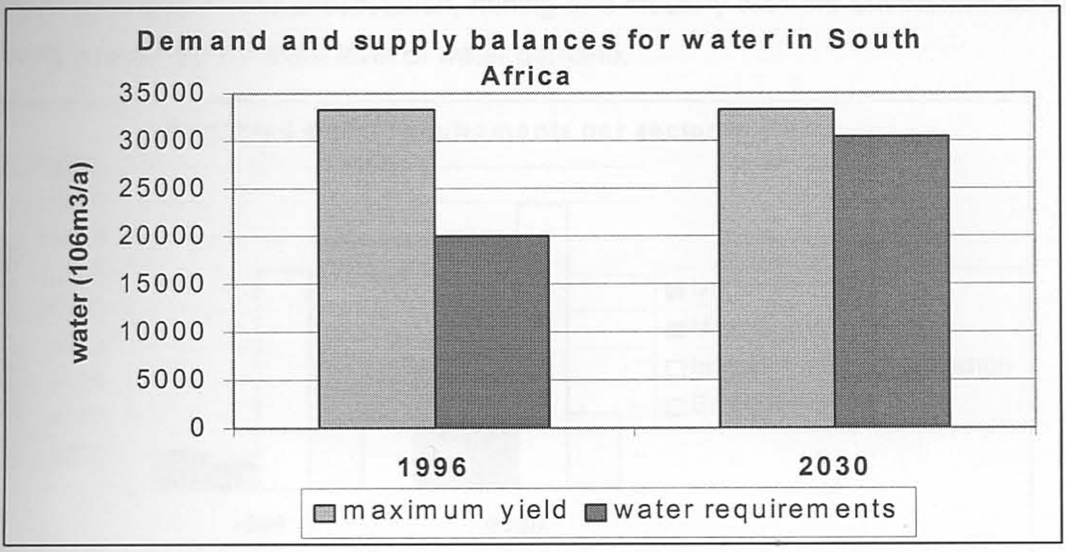

Figure 2-3: Water Demand and Supply balances over time in South Africa, without inter-basin transfers included

Source: Basson et al, 1997

The scenario depicted at a national level in figure 2-3 is disaggregated by region including the impacts of inter-basin water transfers in figure 2-4. It shows that the Northern, South Western and Central regions will be faced with the greatest water pressures by the year 2030. This is expected as these areas are projected to be the largest economic growth areas. The Eastern Inland and Eastern Coastal regions are depicted to be more water abundant in terms of meeting the regional demands.

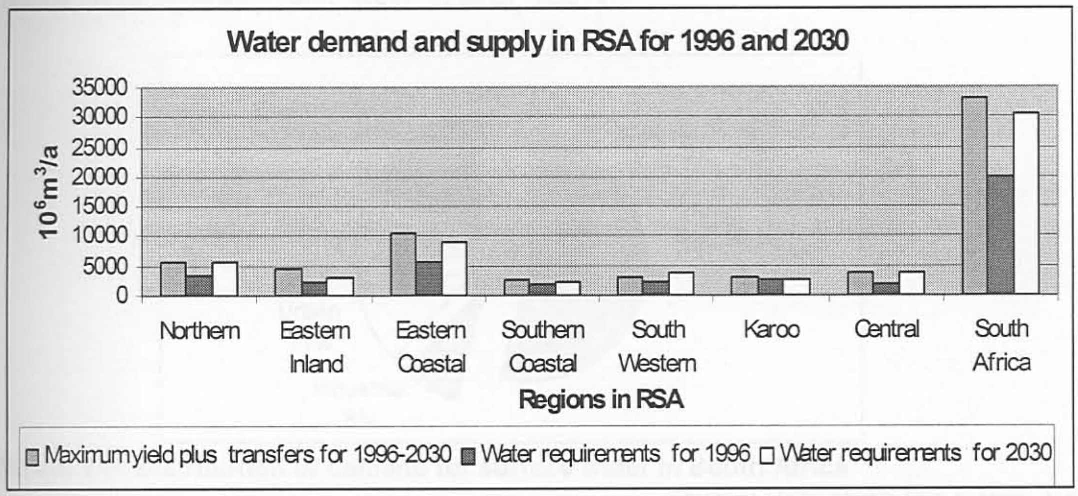

Figure 2-4: Past and projected sectoral growth for water demand in South Africa

Source: Basson et al, 1997

Regional growth in water demand is often also indicative of sectoral growth, the disaggregated demand for water by sector is shown in figure 2-5. The urban and domestic sectors are predicted to be the largest growth sectors from 1996 to 2030, followed by irrigation and afforestation, mining and industry with the environmental sector showing a relatively constant level of water demand.

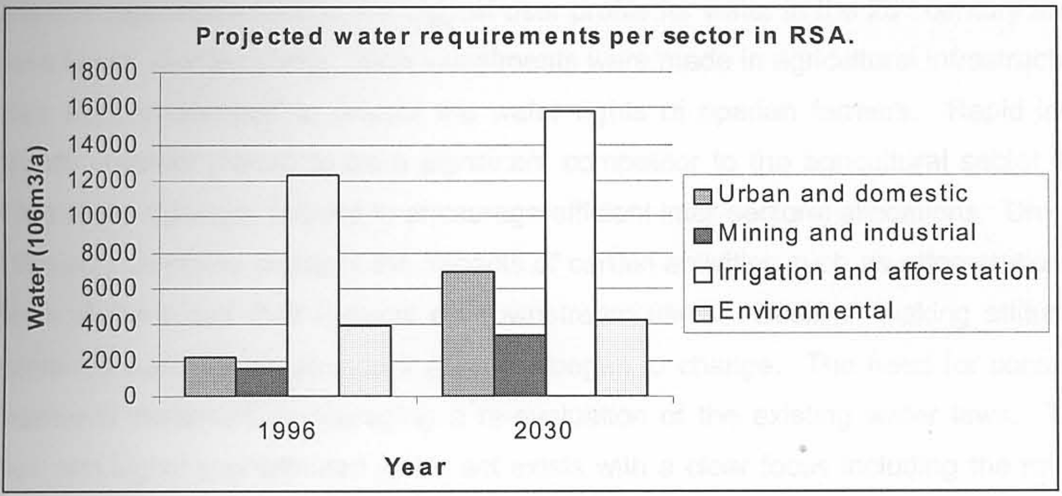

Figure 2-5: Projected water requirements per sector in South Africa

Source: Basson et al, 1997

The five major water-using sectors in the country are agriculture, industry, urban, afforestation, and the natural environment, figure 2-6. Irrigation agriculture represents 54 per cent of the total water demand in South Africa and is mainly consumptive use. Both the industrial (including mining) and the afforestation sectors use eight per cent of the total surface water respectively. The urban and domestic water use estimate is associated with major metropolises and does not include rural domestic supplies (Haasbroek and Harris, 1998; DWAF, 1986; Basson et al, 1997).

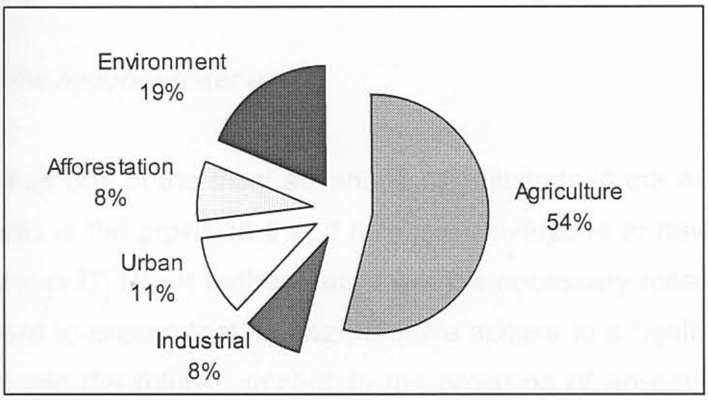

Figure 2-6: Distribution of demand for surface water in South Africa

Source: Haasbroek and Harris, 1998

2.2.4 Water policy

Water legislation and policy in South Africa aims to ensure some level of access to water is attained for all people, in an equitable manner. Water resources are to be managed and used in a sustainable manner now and into the future.

With a structural governmental policy focussed on food production and national growth, irrigation agriculture formed the biggest user profile for water in the 20th century and it still does today. Consequently, large investments were made in agricultural infrastructure and laws were established to protect the water rights of riparian farmers. Rapid industrial growth however proved to be a significant competitor to the agricultural sector and the 1956 Water Law was passed to encourage efficient inter-sectoral allocations. Droughts in 1966 only served to highlight the impacts of certain activities such as afforestation on the flows of rivers and their impacts on downstream users. Decision-making attitudes that perceived water as an abundant resource began to change. The need for conservation measures increased, encouraging a re-evaluation of the existing water laws. Today a new and highly sophisticated water act exists with a clear focus including the role of the environment and water demand management strategies.

The Water Act of 1956 (Act 54 of 1956) vested the powers for water management in a centrally controlled body. Although water shortages were foreseen, planning focussed on the development of extensive water schemes and inter-basin transfers. Pricing was highly subsidised especially for certain sectors such as agriculture and aimed mostly at cost recovery. Water rights were vested in riparian-land owners and all groundwater belonged to the land under which it flowed. By classifying groundwater in this way, it was perceived to be a private resource, which in turn limited opportunities for its further development. As a result, water management strategies were not equitable or particularly efficient.

2.2.4.1 The new national water act

South Africa has one of the most advanced constitutions in the world. An integral part of its Bill of Rights is the provision that it makes for *everyone to have the right of access to sufficient water (s27(1))*. It further states that the necessary measures must be taken by the government to ensure that its citizens have access to a healthy environment that will be sustained into the future. Implicit to the provision of an environment that facilitates well-being, health and environmental sustainability is the provision of reliable, clean water.

Consequently, the focus of the National Water Act is on the development of a comprehensive framework for water resources management that reflects the social, economic, and environmental objectives of the nation (DWAF, 2000). It stipulates that the allocation of water among users (after basic needs and the Reserve requirements have been met) be "guided by social equity and economic efficiency goals" (Hassan, 1998a).

The Reserve refers to the quantity and quality of water necessary to satisfy basic human water needs and protect aquatic ecosystems. Another important aspect of the act is the provision it makes for water demand management and the use of economic incentives for water management. It states that "the Minister may establish a pricing strategy for charges for any water use (s56)", (DWAF, 2000). The recently published pricing strategy for raw water user charges (Government Gazette 1999) identifies economic mechanisms such as: the imposition of economic charges, water licence auctioning, and the establishment of water markets as possibilities for ensuring allocative efficiency among users (DWAF, 2000).

The Act further provides recommendations on the following:

- Forecasting water demand
- Strategies for service provision
- Policies on water rights, cost recovery, pricing investment, private sector roles, environmental protection and restoration
- River basin activity and relationships
- Interrelations between water sources
- Integrated basin and watershed management

2.2.4.2 The Water Services Act

Passed in December 1997, the Water Services Act provides prescriptions on water services and sanitation issues, including tariff structures and management institutions. It establishes an individual right of access by each South African to water supply for basic needs and sanitation, while concurrently addressing conservation needs. Various water bodies and institutions such as: water service authorities, water service providers, water boards and water service committees are expected to include measures in their policies that will realise these rights for the nation. The water services act also outlines norms and tariffs for water services. These norms and tariffs directed by the standards of the Department of Water Affairs may differentiate on an equitable basis between:

- Users of water services,
- Types of water services,
- Geographic areas and their characteristic socio-economic and physical attributes.

Tariffs are also expected to address concerns of social equity, financial sustainability of the service, cost recovery, returns to invested capital, and drought relief or flood protection (DWAF, 1997).

Two concepts arise from the National Water Act and the Water Conservation and Demand Management National Strategy Framework, namely, 'water conservation' and 'water conservation and demand management'.

Water conservation is defined in the act as the *efficient use and saving of water, achieved through measures such as water saving devices, water efficient processes, water conservation and demand management, and water rationing (s1(1)(v)).* The Water Conservation and Demand Management National Strategy Framework however, includes in its definition of conservation the care and protection of water resources. It states that water conservation is the *minimisation of loss or waste, the preservation, care and protection of water resources, and the efficient and effective use of water (p12) (DWAF, 1999; DWAF, 2000).* Both provide a policy prescription for the efficient and effective use of water.

Defined as *the adaptation and implementation of a strategy (policies and initiatives) by a water institution to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability* by the Water Conservation and Demand Management National Strategy Framework *(DWAF, 1999).* Water conservation and demand management rather provides a management tool through which conservation policy goals can be achieved.

The largest water demand sectors (agriculture, urban, and industrial) have already began implementing water demand management techniques. They have however, proven to focus mainly on specific singular approaches, rather than on integrated demand management that incorporates not only technical solutions such as leak detection and maintenance, but also economic and social incentive based approaches.

Economic and social sectors also vary greatly within South Africa. This is evidenced through the diversity of water supply systems and the sources of these supplies; the cost structures associated with different levels of assurance and the spatial locations of supply; the diverse sectoral needs; the ability to pay by different social groups, and the behavioural responses of these groups and sectors within the country. Consequently, water demand and supply gaps need to be carefully evaluated for each sector and each water management area. Water demand management strategies will prove to be more efficacious if they are implemented in a holistic manner, combining social, technical and economic tools to elicit desirable responses.

The implementation of water demand management within South Africa requires further investigation into the following areas:

- Information on water use in each sector
- Institutional frameworks and water authorities, so that the correct levels in the management structure may be targeted for implementation and monitoring
- Consumer behaviour and incentives
- The marginal value of water

A number of research efforts on water demand management have recently been completed and a few of them will be discussed further in chapter 3, they are:

- The Lower Blyde River Irrigation Network
- The Greater Hermanus Water Conservation Programme
- The Working for Water Programme

In conjunction with the new Water Act, increasing public awareness and the threat of a water scarcity crisis, water demand management approaches are expected to achieve great cost savings and user efficiency. The expected outcome will be the availability of a resource, previously allocated elsewhere, for the development of marginal sectors, the protection of the environment, and the servicing of basic human needs within the country.

2.2.4.3 *Pricing practices in South Africa*

It is expected that all significant water resource use within South Africa will be charged for irrespective of where it occurs, this will include the use of water for disposing of effluent and the intercepting or re-directing of water that affects downstream users (DWAF, 1997a). The government is aiming to achieve realistic water pricing objectives for uses other than for basic human needs within a reasonable timeframe.

Numerous costs are incurred in supplying water to different users or in making it available at a source within South Africa, they are the following (DWAF, 1997a; 1997c),

- *The costs of operation and maintenance of publicly-provided schemes.*
- *Capital costs, comprising a return on paid-up assets, the repayment of loans and, in some cases, contributions to a fund for new schemes to make sure that they do not cause sudden tariff increases.*
- *Overheads such as the administration and support required to operate such schemes.*
- *An allowance to provide for depreciation, replacement or refurbishment.*
- *Catchment management costs.*
- *Social and environmental costs.*

As mentioned earlier, water is a good that is necessary for the perpetuation of life and hence it may be necessary for government to subsidise water for certain users. Government policy for water services recognises that subsidies have been allocated historically to many economic sectors in order to support development. With the new focus on pricing water efficiently and equitably, many of these subsidies need to be re-addressed. However, a basic policy framework exists that will support the subsidisation of basic water and sanitation provision services as follows (DWAF, 1997a),

- *Government subsidies will be made available to communities that cannot otherwise afford minimum water supply and sanitation services.*
- *Subsidies will only be available to cover the cost of minimum services provision and will not cover operating and maintenance costs.*
- *Other subsidies provided by the Department of Water Affairs and Forestry for water supply and sanitation provision will be phased out, particularly in respect to operation and maintenance costs, except in cases where subsidies are required in the public interest such as for the protection of the environment.*
- *Subsidies will normally be paid to local authorities or statutory Local Water Committees, rather than direct to a service provider.*
- *The amounts of subsidies will be determined locally by the actual cost of providing basic services.*

This approach to subsidisation is however, dependent on the number of households to be *served* and the *cost of supporting such provision.*

Another component of water pricing that is currently recognised in South Africa is that of resource scarcity and resource economists purport the need to price the resource at a level that reflects this scarcity while concurrently, providing the first six thousand litres of water for essential needs, free of charge.

2.2.4.4 Integrated catchment management agencies

Historically, water management at a regional level has been carried out by offices of the national department. According to Principle (23) of the White Paper on Water Management (DWAF, 1998), "the responsibility for the development, apportionment and management of available water resources is to be delegated to a catchment or regional level in such a manner as to enable interested parties to participate". This in turn requires investment in technical and managerial expertise at these levels of decentralization, so that the national objectives of a more responsive and effective water management process may be achieved. Support from the National Department in the form of capacity building and effective monitoring is expected to facilitate the process of decentralization, ensuring that equity and corrective action goals are strengthened.

i) Catchment management agencies and committees

Central to the implementation of the new Water Act is the establishment and supported functioning of Catchment Management Agencies (CMAs), by the national department, as and where conditions permit. Such agencies are expected to have a wide range of functions delegated to them "depending on the requirements of the specific catchment(s) and systems within their jurisdiction, their capacity to undertake the management tasks, and policy decisions on the overall approach" (DWAF, 1998).

The roles of CMA's will include the following:

- Control over dams for recreational and conservation purposes based on national guidelines and standards.
- Serving the interests of equity, corrective action and the optimum use of water.
- Governance structures will be responsible for the effective management of the catchment area, while addressing the interests of various stakeholders.
- Become financially viable in line with the new approach to water pricing policy.

ii) Catchment management plans

Catchment or system management plans have been proposed in order to facilitate water management at a regional or catchment level. They are expected to be drafted by the respective CMA's in consultation with all stakeholders, under the guidance of the nationally determined framework. These plans will include details on the following:

- water allocations,
- the requirements of the Reserve and international obligations,
- the main issues affecting water quality and quantity which require intervention,
- management goals for addressing the critical issues, and
- potential management strategies and responsibilities for action to achieve these objectives,
- financial arrangements.

CMA's will comprise of various water organisations such as water boards, irrigation boards and other stakeholders. Organizations that are already established and display historical competence in water management decision-making, are more likely to continue in these roles acting in the capacity of a CMA (DWAF, 1998).

2.2.4.5 International obligations / agreements according to the NWA

South Africa's water management strategy includes another vital component, the implications for shared water resources. International customs and practices are adhered to for the management of trans-boundary water resources and various protocols are recognised in the efforts to facilitate regional co-operation, such as the SADC Protocol on Shared Water Course Systems. Other international agreements are outlined below:

"South Africa is playing an active part in the development by the International Law Commission of new rules to regulate the use of non-navigable rivers under the auspices of the General Assembly of the United Nations. South Africa is also signatory to several international protocols which are important for water management policy, such as the Ramsar Convention on the Protection of Wetlands, the Convention on the Elimination of All Forms of Discrimination Against Women (CEDAW), and the Convention to Combat Desertification" (DWAF, 1998).

2.3 Water availability and use in Tshwane

In order to address these shifts in water management regimes and provide a clearer picture of the role of water demand management, the Tshwane municipality was selected as a case study. The nature of water resources and management structures within Tshwane are outlined in this next section. During the year 2000, the greater Pretoria Metropolitan Area was renamed using the authentic African name for Pretoria – Tshwane, and became known as the City of Tshwane Metropolitan Municipality. This new municipal area increased its area of jurisdiction and includes the following local authorities:

- Greater Pretoria Metropolitan Council
- City Council of Pretoria
- Town Council of Centurion
- Northern Pretoria Metropolitan Substructure
- Various local area committees and representative councils such as: Ga-Rankuwa, Mabopane, Themba, Hammanskraal and Pienaarsrivier.

Data for this study was collected for the period July 1995 to June 2000, and is therefore based on the former municipal boundaries for the Pretoria Municipality and not the newly recognised boundaries of Tshwane. It is also important to note that post 1994, Attridgeville and Mamelodi became part of the reporting and billing structure of the Pretoria Municipality for municipal services, hence they are included as an intrinsic part of the study. Therefore, many of the statistics listed below refer to the former Pretoria Municipal area and not specifically to the City of Tshwane. The data used in the estimations was collected from the Pretoria Municipality. In keeping with the initiatives of the South African government and the name changes to many areas within the country, this study will continue to refer to the study area as Tshwane, while asking the reader to keep in mind that the outcomes of this study are based on the municipal boundaries for which the former Pretoria municipality maintained records.

The metropolis of Tshwane – capital city, Pretoria, is the governmental and diplomatic centre of the country. It is situated on the main air, rail and road routes approximately 60 kilometres north of Johannesburg and lies about 1,310 meters above sea level (see figure 2.7). It has a population of 1,057,825[4] living within its municipal boundaries and forms part of the Gauteng Province. The former Pretoria municipal area covers about 70,319 hectares of land. The city is known for its estimated 70 000 Jacaranda trees. The region is highly dependent on the Vaal-Harts river system for the majority of its water. The

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[4] This population figure pertains to the estimate at 30/6/99, (Pretoria City Treasury, 2000).

system is a closed system and as a result, quality controls are stringent. The Tshwane Municipality draws its water from bulk suppliers such as Rand Water as well as from its own supplies of surface water (the Roodeplaat and Rietvlei dams) including underground aquifers. The evaporation in the Johannesburg and Tshwane metropolises is twice as high as the observed rainfall.

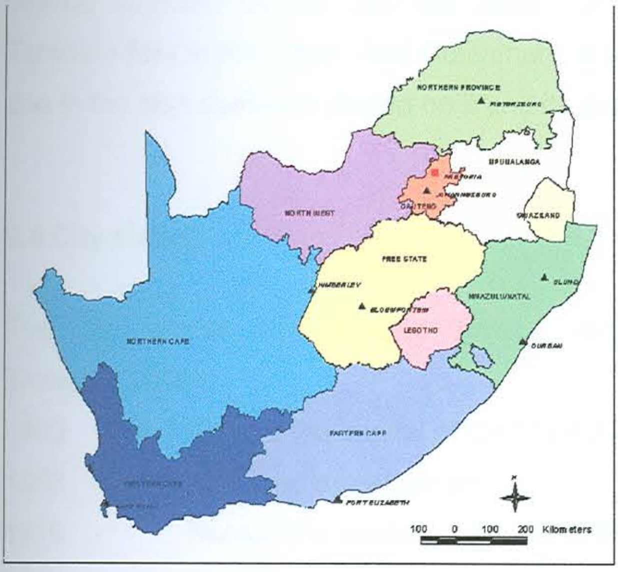

Figure 2-7: Map of South Africa emphasising Tshwane and the capital Pretoria

Source: Own picture, CSIR, 2001

2.4 Growth within Tshwane

Growth within the former Pretoria municipal boundary has been substantial over the past ten years and is shown in the following table:

Table 2-2: Growth of the Pretoria Municipality from 1989 to 1999

Sector of growth	30-06-1989	30-06-1999	Change (%)
Area of Pretoria	63,25 ha	70,32 ha	+ 5.29
Population	848,870	1,086,075	+ 12.26
Total income	774,613,824	2,890,323,000	+ 56.87
Total expenditure	766,799,920	2,789,225,000	+ 28.00
Number of employees	13 159	10 178	- 12.77
Number of street lights	47 623	58 000	+ 9.82
Average monthly water consumption	6,176,803 kl	8,742,048 kl	+ 17.19
Number of electricity consumers	140 394	213 668	+ 20.70

Source: Department City Treasury, 2000

The statistics above indicate that the overall income to the municipal area has increased by fifty-seven percent between the period 1989 and 1999, simultaneously with a population growth of twelve percent and an increase in expenditure of twenty-eight percent. In line with these growth figures, municipal services such as the number of street lamps, water consumption and electricity consumption have also increased substantially at a rate of between ten and twenty percent, thereby placing further pressures on an already stressed natural resource base. In particular, the water resource base, as Tshwane falls in the upper Vaal Catchment, a system that is already regarded as 'closed' due to the high demands placed on it and its dependency on water imports.

2.5 City status

The city's status was founded through various steps as follows (Department City Treasury, 2000):

1860 - Named the capital of the "Zuid-Afrikaansche Republiek".
1903 - Achieved municipal status.
1910 - Named the municipal capital of the Union of South Africa.
1931 - Obtained city status.
1961 - Maintained status as the administrative capital of the republic of South Africa.
1997 - The west block of the municipal building was destroyed by fire on 3rd March. The total loss amounted to about R500 million.
2000 - Pretoria municipality name changed to the City of Tshwane and increased its judicial boundaries.

2.6 Water supply for Tswhane

The City of Tshwane receives its water from numerous sources, ranging from fountains and boreholes to water boards. Table 2-3, shows the disaggregation of water supplied by source, for the city. Own source refers to groundwater supplies and to dams owned by the municipality, the water rights for which they have acquired, based on historical use rights. Some of their water is purchased directly from the Rand Water Board and some of it is classified as losses through delivery.

Table 2-3: Water supply by source as a percentage of the total.

Supply Point	1995/96	1996/97	1997/98	1998/99
Supplied from own source (%)	24.31	24.10	22.76	24.70
Supplied from own source (kl)	28,011,934	31,355,550	32,611,278	35,106,421
Purchased from Rand Water (%)	75.69	75.90	77.24	75.30
Purchased from Rand Water (kl)	87,235,856	98,728,017	110,683,121	107,011,509
Losses (%)	(2.50)	(0.37)	(0.37)	(3.20)
Losses (kl)	(2,960,220)	(483,470)	(542,060)	(4,535,533)
Net total water supply (kl)	112,287,570	129,600,097	142,752,339	137,582,397

Source: Department City Treasury, 2000

* kl represents kilolitre

The dependency for water supplied from Rand Water increased marginally from 1996 to 1998 by 1.98 percent, but has since declined with a greater reliance shifting to the city's own water supplies for 1999. Losses were contained for the period 1996 to 1998 but have since increased by 2.83 percent for the period 1998 to 1999.

A recent development in the supply of water to households in the Tshwane Metropolitan Area, based on the Water Act, is the supply of water for basic needs 'free of charge'. The proposed marginal pricing structure is as follows (figure 2-8):

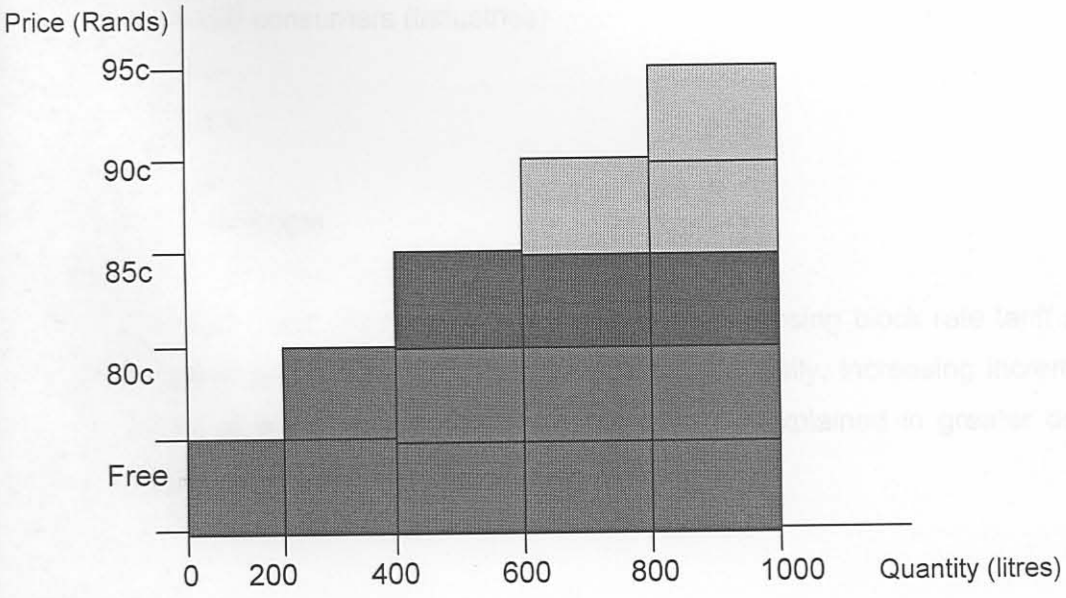

Figure 2-8: Pricing structure for Tshwane water supply

Source: Tshwane News, 2001

Translating into the following costs for a one month period of thirty days (table 2-4),

Table 2-4: Marginal costs for domestic water needs in the Tshwane Municipality

Monthly consumption	Monthly cost					Total cost
	1st 200 (litres)	**2nd 200 (litres)**	**3rd 200 (litres)**	**4th 200 (litres)**	**5th 200 (litres)**	
200 l * 30 days = 6 000 litres	Free	-	-	-	-	Free
400 l * 30 days = 12 000 litres	Free	R 24	-	-	-	R 24
600 l * 30 days = 18 000 litres	Free	R 24	R 26	-	-	R 50
800 l * 30 days = 24 000 litres	Free	R 24	R 26	R 28	-	R 78
10 000 l * 30 days = 30 000 litres	Free	R 24	R 26	R 28	R 30	R 108

Source: Tshwane News, 2001

2.7 Consumer categories

Water consumption in Tshwane is recorded under eleven consumer categories, namely (Department City Treasury, 2000):

- Agricultural areas and farm holdings
- Domestic dwellings
- Other consumers
- Flats
- Domestic businesses
- Old age homes
- Large scale consumers (industries)
- Mamelodi
- Attridgeville
- Centurian
- Voortrekkehoogte

Water is metered and charged for according to an increasing block rate tariff system. A lower charge is set for the first 0,2kl water consumed daily, increasing incrementally for larger blocks of water consumed, these rates will be explained in greater detail in the methodology and results chapters, chapter five and six.

2.8 Summary

The face of water resources management within South Africa is changing rapidly. Recognised as a world leader in its approach to water resources, the national government is actively striving to implement the theoretical principles on which the National Water Act is based, at a practical level. At the heart of this very goal lies the need to price water correctly, including operation and maintenance costs, delivery costs and some level of pricing for the scarcity value of the resource itself. Tshwane was selected as a case study because it is an established city dependent on a highly stressed water system. The underlying management approaches to water resources are discussed in the following chapter, chapter three. It is in this context that the role of price elasticities of demand for water becomes evident.

CHAPTER 3: DEMAND MANAGEMENT AS A TOOL FOR EFFICIENT WATER ALLOCATION AND USE

3.1 Introduction

Due to the nature of water resource's and the importance of water for the perpetuation of life; interventions through supply or demand management are required in order to meet the associated social and economic goals, such as: efficacy, economic efficiency, equity, environmental impacts, fiscal impacts, political and public acceptability, sustainability and administrative feasibility (Hassan, 1997b). For a greater discussion on these goals, see appendix 1.

However, as supply-side interventions are becoming increasingly costly and less viable, water demand management interventions are being adopted at a global level, to meet increasing demands (Haasbroek and Harris, 1998; Darr et al, 1976; Hassan, 1997b; Tate and Kassem, 1992; World Bank, 1995). Simply put, water demand management aims to achieve the efficient allocation and use of water resources. This includes interventions at three levels of water management, namely, allocation, application and productivity (Ashton and Turton, 1999).

The ability of water management institutions to adopt and adapt to these changing philosophies will inevitably determine the success or failure of demand management strategies. What constitutes water demand management? What set of tools are available for applying water demand management (WDM)? Will these tools address the limitations of water scarcity and is there a role for WDM in the future? This chapter aims to address some of the frequently asked questions surrounding WDM, with specific focus on the role of water pricing and value for the South African water sector.

This chapter is structured as follows. The first part outlines the approaches to water demand management by identifying non-market and market mechanisms. The second part introduces the concept of water demand curves and elasticities and their role in assisting decision-making for water management. The third part develops the argument into a discussion on the value of water.

3.2 Water demand management

As the marginal costs of water supply options become increasingly higher in the face of declining supply availability and accessibility and water utilities focus on cost recovery requirements above subsidisation needs, water demand management is proving to be a preferred and practicable solution. Rising regional water scarcity in many parts of the world further exacerbates the water supply problem as countries become more hesitant to offer water to neighbouring regions and more determined to secure their own positions thereby reducing their water shortage risks. Economic development activities pressurise the system further but also provide advanced technology options and economies of scale that support the underlying methodology for water demand management (Goldblatt et al, 2000; Haasbroek and Harris, 1998).

Defined by Goldblatt et al (2000), water demand management is "a management approach that aims to conserve water by controlling demand which involves the application of selective incentives to promote efficient and equitable use of water". This approach encourages water to flow to its highest value use and to be allocated equitably between user groups.

Water demand management approaches provide a means by which user demands may be satisfied without resorting to costly and timely supply-side development. It aims to build efficiency into the system by modifying demand. This incorporates both technical efficiency and economic efficiency, the former targeting the technical aspects of water allocation between user groups and various sectors, the latter targeting the maximisation goals of the benefit-cost ratio between various demand management options (Goldblatt et al, 2000). Two approaches to demand-side management have been identified, the use of market and non-market incentives to influence user behaviour. The most popular market incentive depends on pricing (water tariffs) followed by water markets, auctioning and pollution charges. Non-market incentives such as restrictions, education and persuasion, and quotas and norms may also prove beneficial, but have generally been evaluated in conjunction with pricing changes, as a result their direct impacts are often difficult to identify (Winpenny, 1994). WDM provides a set of management tools through which conservation policy goals can be achieved such as:

- Waste reduction
- The use of water based on economic efficiency principles
- The application of water efficient methods and appliances

- Identification of behaviour altering incentives
- Service cost recovery
- Allocation priorities and movement from low value users to high value users
- The role of the private sector
- Decentralisation of management and control
- The use of economic instruments such as prices and markets to achieve efficient allocation of the resource
- The use of other instruments such as regulation, moral suasion, and technology to reduce water loss and waste

Water demand management is superior to approaches based on supply augmentation as it provides clear economic, financial and environmental benefits, while attempting to relate the value of water to the cost of provision. It also negates the need for future new supply developments by reducing water waste, inefficiencies and loss. In turn, environmental disturbances are minimised and capital resources are 'freed up' for investment in other priority areas (Haasbroek and Harris, 1998; Winpenny, 1994). As a result, water demand management addresses efficiency and equity goals. The Southern Africa Water Demand Management Declaration of March 1999 (Appendix 2) depicts the intentions of water demand management for the SADC region (Goldblatt et al, 2000), in turn emphasising the role for WDM in the region.

3.3 Non-market mechanisms in WDM

Non-market mechanisms are used to influence consumer behaviour without resorting to pricing or market mechanisms and to reduce losses and waste through conservation measures. They include repair and maintenance of infrastructure, moral suasion, public education, standard setting and the establishment of norms.

3.3.1 Restrictions and sanctions

Although pricing policies are increasingly being adopted to address issues of water resource management, they still play a relatively minor role in water shortage management. Drought management is more commonly dealt with through direct legislation such as daily service interruptions or various systems of quantity rationing. These forms of regulation serve to curb water demand and use by limiting the quantity of water used, the time-period of allocation, or the specific category of water use.

Restrictions prove to be valuable mechanisms for curbing water demand, however the effects are short lived. Once restrictions and sanctions are removed, water use patterns tend to return to their former levels due to the observations that the underlying consumer behaviours that drive these demands remain unchanged, as do the requirements of existing water-using fixtures (Goldblatt et al, 2000). Hence water demand management principles based solely on regulatory mechanisms tends to achieve short-term goals.

A series of water demand management country studies were carried out for Southern Africa under the guidance of the International Union for the Conservation of Nature during 1998. From these country studies, it is evident that restrictions have been widely used within the region during times of severe water shortages. Zimbabwe enforced restrictions on the rights to redistribute water during 1992. Botswana enforced restrictions on the uses of water for construction purposes and household irrigation during the 1980's. South Africa also imposed restrictions during its drought periods specifically targeting household use by setting times for irrigating gardens or complete bans on irrigation for recreation or aesthetics during 1984, (Arntzen et al, 1998; Buckle, 1998; Gomes et al, 1998; Haasbroek and Harris, 1998; Goldblatt et al, 2000).

Woo (1992) recognised that there was very little empirical evidence on the effects of water service interruptions and developed and urban water demand model that included the effects of daily service interruptions in Hong Kong. The model was estimated using monthly per capita data for Hong Kong for the period 1973 – 1984. Aggregate data was used as information was lacking for consumption by rate class breakdowns such as commercial and residential. Residential and non-residential water consumption was billed under inverted block rates and flat charges per cubic meter respectively. Six regression models were estimated including the double log and linear functions eliminating the possibility of spurious results. The Hausman specification test was applied to remove any biases or inconsistencies caused by endogenous price variables. The double-log and linear models were shown to be plausible models for explaining per capita water use in Hong Kong. The findings indicated that the effects of service interruption on per capita consumption were significantly small. Furthermore, the own price and income elasticities estimated were –0.3840 and 0.2776 respectively, indicating that price responsiveness was highly significant and that "price does matter, even for Hong Kong consumers whose use patterns are unrelated to residential and agricultural irrigation." A price increase of 16 to 30 per cent would have achieved the same consumption results as the service interruptions.

3.3.2 Quotas and norms

Quotas and norms may be set to achieve allocative efficiency goals in the face of scarcity. Both fixed quotas and penal tariffs may be used to enforce rationing. In Israel, water consumption fell by 70 percent over the period 1962 to 1982. The reason was the use of a comprehensive system of norms taking into account "best practice technology". Users who exceeded these limits were fined accordingly Arlosoroff (1985) in (Haasbroek and Harris, 1998). Large water savings have also been recorded in Tianjin, China through recycling and norms based on water audits Bhatia et al (1993) in (Haasbroek and Harris, 1998).

3.3.3 Education and moral suasion

The raising of public concern through exhortation and appeals is often used in conjunction with other approaches, particularly for the management of drought, hence it is difficult to quantify their individual impacts (Winpenny, 1994). Water use awareness and efficiency education for irrigation agriculture has not been widely evidenced despite the demands of this sector on water and its inherently low water application efficiencies (Goldblatt et al, 2000).

Three extensive programs were implemented in selected areas within South Africa as pilot studies for future work on water demand management. The first approach to water management was to upgrade the existing earth-lined irrigation canal system belonging to the Blyde River Irrigation Board, by replacing it with a buried pipeline, thereby reducing leakage losses (Ballot, 1997).

The second approach was the implementation of a twelve-point demand management plan for the Greater Hermanus region, as follows:

- Intensive communication campaign
- Education and water audits at school
- Water loss management
- Clearing of invasives in the catchment
- Water wise gardening
- Water wise food preparation
- Domestic water saving initiatives
- Regulations

- Assurance of supply tariffs
- Escalating seven-step block rate tariffs
- Informative billing
- Masakhane metering project

This integrated demand management approach to water conservation proved to be highly successful (Haasbroek and Harris, 1998).

The third approach to water demand management was the multi-agency Working for Water programme. A comprehensive initiative aimed at clearing invading water 'thirsty' alien plants over a period of 20 years. The initiative recognised that exotic plants had invaded about ten million hectares of South Africa's land surface due to the careless introduction of these plants for commercial gain. These plants impact on the environment by obstructing rivers, increasing soil erosion, threatening indigenous biodiversity and absorbing water on a perennial basis. The Working for Water Program has hired many disadvantaged citizens and provided them with a wage to remove these invasive woody species. The program is however, wrought with various controversies as many indigenous trees are removed along with exotics. This approach is sometimes confused with supply-side management but for the purposes of this study supply-side management is regarded as any means by which water supply is augmented through large infrastructural projects such as the building of dams. Demand management is explained as any approach that increases the availability of water through managed responses in its use and application hence the working for water programme is a good example of a demand managed approach to extending the available supply of water.

3.3.4 Technology improvements

Water efficiency may be greatly improved through the introduction and application of water saving technologies ranging from crop selection and irrigation system changes in agriculture, to the choices of cooling systems in industry and the fitting of low water use appliances in households. The feasibility of improved technology being implemented is however often limited by capital constraints (Goldblatt et al, 2000; Haasbroek and Harris, 1998).

3.3.5 Water loss control

Many of the water systems are characterised by leakages and 'lost water'. Through the control and estimation of this unaccounted-for water, water may be saved at the level of the water service provider. Approaches to water loss control include ongoing leakage detection, ongoing program repair, water audits, pipe replacement and water meter management (Goldblatt et al, 2000).

3.3.6 Water re-use and recycling

The treatment and re-use of wastewater 'frees up' water that would otherwise be 'useless' to certain sectors, thereby reducing the need to augment supplies through costly supply-side management approaches. Water re-use and recycling can be achieved in numerous ways such as through:

- Re-use plants[5],
- The use of wastewater as cooling water in power plants,
- The diversion of industrial and toxic waste water away from main water courses,
- Specialised treatment of wastewater,
- Specialised treatment of effluent with strict quality controls,
- Water mixing that combines wastewater with water from other sources,
- Using waste-water for irrigation.

Many opportunities exist for the re-use and recycling of wastewater within the agricultural, industrial and domestic demand sectors (Arntzen et al, 1998; Buckle, 1998; Haasbroek and Harris, 1998; Gibbons, 1986; Goldblatt et al, 2000; Gomes et al, 1998).

3.4 Market mechanisms in water demand management

Economists frequently prefer to use market mechanisms for allocating goods and services. Water demand management recognises two market-orientated approaches to managing water. The first is the establishment of a water market in which water as a commodity or the right to use water itself may be traded. The second is the selection and implementation of a pricing mechanism that will fully reflect the opportunity costs and scarcity value of water to society. Pricing mechanisms cover a wide range of values for

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[5] For an explanation on re-use, see definitions

water resources and readers needs to be mindful of the distinction between a market price for water rights and consumer tariffs aimed at some level of supply cost recovery.

3.4.1 Water markets and tradable water rights

Historically, water has not been allocated through markets. Coase (1960) in (Munasinghe, 1986) stated that market allocations of resources would be efficient under two conditions. First, property rights need to be clearly defined and well protected. Clearly defined rights are those that are exclusive, specific, enforceable and transferable. Second, transactions costs must be zero or negligible (for further discussion see: Meinzen-Dick et. al, 1997; Rosegrant and Binswanger, 1994; Hassan, 1997; Algheriani, 1994). Despite the recognition that transactions costs in water markets are rarely zero, markets in tradable rights are believed to offer a number of significant benefits:

- Water markets promote flexibility in water use and in response to changes in demand patterns and comparative advantages, with regard to crop prices and water prices. They also help to establish an explicit value for water and provide incentives for efficient use, thereby recognising the full opportunity cost of water (Rosegrant and Binswanger, 1994; Gardner and Miller, 1985).
- Water markets empower water users to make decisions that will maximise their utility and achieve greater social gains. They do however need to develop acceptable definitions of the conditions that trigger service and availability interruptions, as water is not stochastic over time and space (Rosegrant and Binswanger, 1994; Hamilton et al, 1989).
- Where the security of a right to tenure is established, investments in water saving technology will be encouraged (Rosegrant and Binswanger, 1994). Hamilton (1989) however, found that the effectiveness of efficiency gains was dependent on the nature of the alternative use and the corresponding length of tenure. For interruptible water markets that allowed trade between irrigation agriculture and hydroelectric power, a long-term contractual commitment of at least 25 years was required.
- The externalities associated with degradation are internalised (Rosegrant and Binswanger, 1994).

Although persuasive arguments are offered for water markets, their establishment is also subject to a number of critical conditions such as:

- The existence of water rights and some levels of initial allocations that are well-defined and specified in a unit of measurement (Armitage et al, 2000).
- A difference in values for water among users.
- Enforceable water rights that secure the transfer of benefits from the water-use to the rights holder (Armitage et al, 2000).
- Transferable rights (Pigram, 1993; Armitage et al, 2000).
- Technical and physical infrastructure that will allow for the transfer of water from one user to another. Volumetric measuring will allow flexible deliveries in line with demand changes over space and time. The technology need not be extremely sophisticated (Roome, 1995; Meinzen-Dick et. al, 1997).
- The establishment of various supporting institutional and legal frameworks that facilitate the negotiation process, administration duties and a guarantee of title ownership (Meinzen-Dick et. al, 1997; Armitage et al, 2000; Simpson, 1992).
- The existence of voluntary and willing sellers and buyers (Roome, 1995).
- Political support and the establishment of mechanisms to minimise social and environmental impacts (Hassan, 1997a).
- Constraints of scarcity.

The establishment of markets for water has not been met with overarching enthusiasm. Fears of monopoly formation and the limitations of many administrative bodies to handle negotiations and market establishments are some of the concerns. In many countries existing water laws state that water cannot be transferred between sectors, that it must rather be utilised in the purpose and sector for which the right was obtained (Kessler, 1997). Characklis (1999) validated that this ban on inter-sectoral trade or leasing "handcuffed" markets ability to adapt efficiently during periods of drought and suggested that by eliminating this distinction between rights, trade between all affected participants would be encouraged, thereby increasing responsiveness to water scarcity threats. Consequently, many markets function at the margin due to high transaction costs, inadequate infrastructure, poor legal frameworks, and political and social resistance (Montginoul et. al, 1997).

Existing water rights generally form one of three userfructuary systems: riparian rights (link ownership of water to the ownership of adjacent or overlying lands); appropriative rights (acquisition of a right by a priori use over time); and public allocation (water distribution by administrative bodies), (Sampath, 1992; Rosegrant and Binswanger, 1994). Despite limitations in the transferability of these rights in most countries, many have managed to establish markets for water and water rights. Groundwater markets are well established in parts of Asia (Winpenny, 1997); informal water markets and trading, mainly in underground water, is expanding in many developing countries such as Tamil Nadu, Pakistan, Indonesia and Jordan. These spontaneous markets usually reflect 'spot-market' trading of given quantities at given points in time (Meinzen-Dick et al, 1997; Shah, 1991; Chaudhry, 1990; Rosegrant and Binswanger, 1994). Surface water markets exist in some of the western States in the USA such as New Mexico and California; in parts of Australia and in Chile. Progress is also being made in the UK to encourage farmers to trade with others within their districts (Winpenny, 1997; Meinzen-Dick et. al, 1997; Kessler, 1997).

A limiting factor to these emerging markets is the presence of transaction costs (costs of technology, analytical skills, institutional, and legal frameworks). Rosegrant and Binswanger (1994) argue that where the value per unit of water is high for different uses then the gains from trade should offset the transaction costs involved. Hamilton et. al. (1989), concur with this idea that markets facilitate the provision of compensation unlike centrally controlled allocation; and they propose that the level of compensation for the trade should be greater than the income lost by moving the water from its prior use to its current use. Therefore, the value generated by the water use in the new sector must be greater than the income lost including all transaction costs by the water used in the old sector. Markets permit the transfer of water across sectors, districts and time and it is expected that buyers and sellers will have good knowledge about the value of water to their production processes. This in turn is expected to reduce the information costs of the transaction unlike the case where marginal cost pricing is used to allocate the resource (Meinzen-Dick et. al, 1997).

Markets for transferable water rights still face the challenge of incorporating environmental protection and public interest criteria. Externalities such as pollution, overdraft, lower water tables, and waterlogging have yet to be addressed, although theoretically the market system should account for the costs associated with these externalities.

The majority of existing literature on water markets tackles transactions among agricultural users or those transactions between agriculture and urban or municipal users. The study by Hamilton (1989) was one of the first to address the use of water markets to meet hydro-electric demands. Shah (1985 and 1989) in Winpenny (1994) discussed the relevance of groundwater markets, recognising the non-sustainable implications of aquifer depletion. Another, large operating markets scheme was established in the United States – the Colorado-Big Thomson scheme. This scheme negated the necessity to develop further supply-side solutions and effectively addressed supplemental irrigation needs (Howe et. al, 1986).

The new South African Water Act provides a policy framework for water markets in the country, as a means to address issues of water allocation and demand, however it remains unclear regarding the legal transfers of water use licences, relying on a fairly regulated approach to markets that is expected in turn to increase transaction costs (Louw et al, 2000; NWA, 1998). Trade is also dependent on the premise that allocations come from the same source, particularly for the purposes of cross-sectoral trade (Louw and Van Schalkwyk, 2000), and that allocations are value driven. The Water Act also implies that rights must be assigned and water allocated under the perception of fairness, a process inherently depending on the preparation of a water balance per catchment, negotiations on lawful apportionment, and decentralised management. This process may also require some changes to be made in the interests of equity, after which 'free functioning water markets' should be allowed to operate (Backeberg, 1996; Armitage et al, 2000).

Within South Africa water trading in irrigation agriculture exists at an informal level in the north-eastern part of the country, the prices at which water is traded are negotiated by individual farmers and vary accordingly. Discussions are currently underway with the Department of Water Affairs RSA on how to establish water markets under their demand management strategy. Water use along the Orange River has been evidenced by water transfers since the 1980's and indicates transaction costs varying between R2000 and R6000 per farm of 30 hectares, with an allocation of 15000 meters cubed per hectare, excluding the cost of electricity, irrigation infrastructure and brokers fees (Armitage, 1999). The farm survey done by Louw and Van Schalkwyk (2000) revealed that farmers along the Berg River also participated in water trading and paid about 6 cents per meter cubed of water for permanent water transfers. Temporary water transfers were however, carried out frequently on a 'good-will' agreement basis and did not have transaction costs associated. For the purposes of the study, temporary transaction costs of 3 cents per cubic meter were assumed.

The establishment of water permits (transferable right to water use), water banking (the storing of water for the purposes of critical need driven demand) and water auctions (sales of water by authorities to the highest bidders) are also approaches to creating markets under the realm of water demand management. Algahaiani (1994) proposes the use of water banking to Libya based on purely technical reasons, a number of banks have also been established in the USA and have proven to be very successful in meeting demands during periods of drought (Keller et. al, 1992; Kennedy, 1991; Vaux, 1991: in Winpenny, 1994). Water auctions are however very rare as they do not actually transfer legal entitlements to the consumer. Environmental and third party externalities are not reflected in the auction prices. An example of a water auction can be found in Simon et al (1990) in (Winpenny, 1994).

3.4.2 Economic supply pricing of water resources

The notion that cheap water will be wasted and that the correct pricing of the resource will instead lead to it being treated as a precious and efficiently used commodity lies behind the value of pricing in water demand management. Numerous approaches to this question of efficient pricing have been addressed including delivery cost pricing, electricity and pumping cost-based pricing (for groundwater exploitation), marginal cost pricing, opportunity cost pricing, scarcity value, marginal value pricing and value added. Each approach has its shortcomings and South Africa now, not only has to find a way of measuring consumption and valuing its water resources, but must also address the welfare pressures of a large population living without basic domestic supplies and sanitation facilities.

Water tariffs refer to a monetary charge placed on the user for withdrawing water from the bulk supply of water or water services. This usually relates to surface water and government supply-schemes. Depletion of ground water sources does not currently carry a user cost in South Africa. The concept of pricing becomes extremely complex as use activities are considered. In many cases such as industrial use, water is returned to the overall supply and where this water conforms to quality standards, it may be reused. Consequently, charges may take the form of direct extraction charges, coupled with pollution charges and rebates for efficient use. A further distinction also exists between the pricing of water based on water service charges and the pricing of water rights.

Three types of pricing are generally recognised: financial pricing, economic pricing and environmental pricing. Financial pricing focuses on operation, maintenance, servicing and capital investment cost recovery. It is usually reflected in average costs. Economic pricing signals the opportunity cost of water and its consequential costs of allocation between users. It also recognises the costs associated with long-term investment planning, to current and future generations such as opportunity and marginal costs. It, therefore, reflects the scarcity value of water. Environmental costs include the costs associated with the externalities of water use.

Pricing proves to be a valuable tool in determining the willingness to pay of various users. The adoption of a pricing policy does however depend on a number of "trade-offs" such as: economic efficiency goals, investment information, administrative and transaction costs, and equity goals. Pricing also proves to be inappropriate on the grounds of efficiency in the face of resource superabundance (a "free good"), (Hanke and Davis, 1973). Pricing is also limited where it is used in direct opposition to existing policies such as the subsidisation of water intensive agricultural inputs. Questions arise as to whether users should be expected to pay for investment costs as well as maintenance and operation costs and the debate extends to the burden of costs associated with environmental externalities.

Current thinking recognises the existence of numerous criteria and requirements for the setting of water tariffs, some of which are not consistent with others, they are the following (Munasinghe, 1986):

- Economic resources must be allocated efficiently within the water sector,
- Fairness and equity considerations must be met whereby, costs are allocated among water consumers according to the degree to which they impose on the system; price stability needs to maintained from year to year; and water needs to be supplied at a minimal level to consumers who cannot who are unable to pay the full costs.
- Enough revenue to cover the financial requirements of water supply utilities must be raised by water prices,
- Customers need to be able to understand the tariff and billing structures for pricing,
- Political goals also need to be addressed such as the application of subsidies for certain sectoral growth.

Based on these policy goals a myriad of pricing structures have emerged as follows:

3.4.2.1 Financial cost recovery

Historically water has been regarded as a 'free' good and as a result, the provision thereof has been heavily subsidised in many countries, particularly in the agricultural sectors. Users have not been impelled to apply water efficiently, to allocate water between uses rationally or to conserve unutilised quantities of the resource. The recognition of the scarcity value of the resource and the increasing demands for competing use have initiated a move to establish the true economic price of water, thereby reflecting both the opportunity cost and the shadow price of the resource. Water charges are based on the premise of collection, where markets do not exist and administered prices are not used. This is relatively easy for uses that are metered on a regular basis such as industrial, commercial and domestic use. However, extra costs become apparent for uses where water is not metered such as groundwater abstraction and direct precipitation storage.

Historical pricing structures have emphasised cost recovery, among other deficient regimes, such as average cost pricing and flat-rate pricing. The use of tariffs is widespread in many countries, but cost recovery pricing does not from part of demand management (OECD, 1987). Cost recovery fails to incorporate the costs associated with investments as they usually try to recover the delivery costs of the service, depending on central bodies such as governments to subsidise the fixed capital costs. Average cost pricing does not distinguish between the costs of supply of old water projects and new water projects. While flat-rate pricing regimes tend to subsidise peak load and remotely located consumers by failing to adjust for distance, location, seasonal and temporal change impacts on the costs of delivery (Dinar and Subramanian, 1998; Hassan, 1997b; OECD, 1987; Munasinghe, 1988). Cost based pricing is reliant on the underlying country priorities. Failure to monitor consumptive and non-consumptive use and adjust charges accordingly for a resource that clearly has recycling and recovery potential further limits the gains from historical pricing regimes.

3.4.2.2 Delivery cost pricing

Delivery cost pricing refers to the pricing of water based on the costs of delivery. Some existing water pricing methods include (Dinar and Subramanian, 1998; Sampath, 1992; Tsur and Dinar, 1995):

Volumetric: These charges are based directly on the volume of water consumed. These volumes may be determined by the time of known flow or the time of uncertain flow or may be a charge based on a minimum volume whether used or unused.

Output: Charges may be based on the level of output produced through the applications of water. For example, irrigators may be charged a water fee per unit of a particular crop.

Input: Charges based on inputs are the reverse of that above. Here water users are charged per unit of certain inputs used.

Per unit area: In this case water is charged per unit area irrigated and may differ according to the choice of crop irrigated, the season of the year and the choice of irrigation method.

Flat-rate charges: Flat rate charges are based on any number of components such as the number of residents, number and type of water-using fixtures, the number of taps, number of rooms in the house, the width of inflow pipes, measures of property value or even ground value. They often consist of a flat charge for a minimum level of consumption. These systems violate the principals of allocative efficiency, as they do not encourage the use of water in its highest value use. They are however very easy to administer and are fairly simple for consumers to understand, without the need for strict monitoring. Flat-rates also assure a relatively good return of revenue to the water supply institutions (OECD, 1987).

Decreasing block rate tariff: This tariff system is based on the premise that succeeding blocks of units of water are sold at lower prices and usually include some level of minimum charge based on customer and capacity costs. The limitation of this approach is that in some instances it may result in inappropriate cross-subsidisation, whereby excessive water use for luxury purposes such as garden watering or swimming is charged a lower rate than prudent users (OECD, 1987).

Increasing block rate tariff: These tariffs work in the opposite direction to the above-mentioned tariffs and the rate increases for each additional block of water consumed. This approach is aimed at keeping consumers within the lower brackets of quantity demanded.

Two-part tariffs: A combination of flat-rate pricing and average cost pricing form the basis of two-part tariff structures. The flat-rate depends on the characteristics of the consumer such as the size of meter or the number of water outlets. The second part of the tariff is usually a single rate based on the volume of water consumed. Revenue obtained from the volume charge must however, be managed carefully. If it is too low then consumers will be encouraged to overuse the water resource, if it is too high then consumers will be discouraged from demanding the resource and revenue streams to cover the associated costs will become uncertain (OECD, 1987).

Hanke and Davis (1973) recognised that water rates tended to be uniform over space and as a result, delivery costs could not be flat-rates but were valued according to certain variables. They proposed that water commodity prices for urban demand should be varied according to rate zones, based on the consumers distance from the source centre and area demand density. These rate variations were expected to address equity and efficiency goals.

A review of demand management issues for Canada by Tate and Kassem, (1994), recognised that water metering used in conjunction with demand based pricing policies lowered demand by more than 30% of pre-metered levels. The municipal sector was advised to recover the full cost of service provision, while integrating water supply and waste treatment into one service. For smaller communities dependent on subsidies it was proposed that these subsidies be given directly to the consumers. For the case of the industrial sector it was recognised that the prices paid for water should reflect the cost of providing the resource. For water intake, economic rent principles are used for pricing and on the discharge side sewer surcharges, effluent discharge fees and marketable effluent permits were recommended as management instruments.

3.4.2.3 Average cost pricing

Average cost pricing is based on the premise that all costs associated with water delivery are added together and are then divided by the total number of units expected to be sold within the financial year. As a result, all water consumers bear the costs of peak load users throughout the year (OECD, 1987). Where sectors are institutionally underdeveloped, average cost pricing is used as it is simpler, although marginal cost pricing is superior. Average cost pricing tends to be the most widely used policy where meters and commodity charges are established in municipal zones, Hanke and Davis (1973). This approach is regarded as insufficient because historical average costs do not reflect marginal historical or future opportunity costs and are thus inconsistent with the efficiency concept. Gibbs (1978) further purported that the use of the average price per unit of water was limited and tended to overestimate response changes when used in demand models.

3.4.2.4 Marginal cost pricing

Marginal cost pricing is defined in economic theory as a pricing rule whereby "firms or government-owned enterprises set price equal to marginal cost", where marginal cost is the addition to total cost resulting from each additional unit of output (Mansfield, 1994). Facilitated by perfectly competitive conditions and the absence of externalities, economic theory further stipulates that these market prices will reflect social values.

According to Sampath (1992) if long-run marginal cost pricing of water is adopted for the irrigation sector then the resulting social benefits will all be optimal. This will however require the absence of externalities, increasing returns to scale and monopoly power. Furthermore, marginal cost pricing is believed to facilitate improved environmental management through the direct conservation practices of farmers wanting to reduce their overall costs. Sampath (1992) reviews the status of irrigation water pricing and the necessary cost recovery in developing countries finding that the pricing policies are predominantly based on financial and not economic considerations. Price setting levels are aimed at maintenance and cost recovery inhibiting aims to meet the best efficient use objectives for the scarce resource, water. Irrigation charges further diversify between countries and regions within these countries by taking the following forms: demand charges based on volume, water rate per hectare based on the crop irrigated, land taxes based on the provision of irrigation facilities, betterment levies, irrigation and maintenance cess' and other indirect financing mechanisms. Based on the above observations it is evident that most developing countries do not follow marginal cost pricing principles nor optimal pricing procedures. The reasons for this behaviour may be due to a number of socio-political, physical and administrative constraints. Many "indirect beneficiaries" other than the irrigation farmers, such as consumers gain from irrigation and Sampath (1992) proposes that it may not be equitable to allocate the full costs of irrigation water to the farmers alone. Variable pricing systems also carry large administrative costs; they may facilitate efficiency but may not be politically or administratively feasible. Where water has formerly had 'no price' complex cultural issues arise through the introduction of price, furthermore, price elasticities of demand for water are indicated to be low efficiency pricing gains may be negligible. Water pricing is not only used to determine efficiency but may also be required to meet policy objectives of conflict resolution, income redistribution and rural development. Finally, Sampath (1992) indicates that deviations from marginal cost water irrigation pricing may not necessarily be inefficient, in cases where "rainfall, water supply, crop production functions and effective demand" are evident at certain levels he recognises that market clearing prices may differ from marginal cost.

Winpenny (1994) defines long-run marginal cost pricing where price equals marginal cost or supply, in other words where the marginal benefit of consumption is equated with the marginal cost of supply. This form of pricing is regarded as the most common but relies upon metering and the proportionate volumetric charges; these charges should also include all related environmental costs and benefits to be strictly economically efficient.

While reviewing the potential for marginal cost pricing in water resource management Hanke and Davis (1973), recognised that marginal cost pricing was the most effective form of pricing to achieve the efficient allocation of natural resources. Furthermore, that marginal cost pricing will achieve social welfare maximisation where the difference between total revenue plus consumer surplus and opportunity cost is the greatest. Thereby optimal output from an existing water facility may be achieved while determining future investment capabilities. Hanke and Davis (1973) clearly identify the marginal cost concept as that of marginal opportunity cost, maintaining a useful distinction, especially for the case of water. Where water use is defined by a plethora of competing users, its price should reflect, delivery, maintenance and treatment costs but also the costs of not using the resource in its best alternative use. A number of areas were identified that could respond favourably to revised pricing strategies namely, municipal water services, industrial and municipal sewerage, navigation, flood damage reduction and shoreline protection.

Municipal water service revenues were predominantly derived from flat rate charging systems, in cases where certain municipalities were partially or wholly un-metered. They found that this approach did not lead to conservation practices and that efficiency gains were lost resulting in the marginal opportunity cost of water provision bordering on a zero value. Furthermore water is mobile and is characterised by variability over time consequently it was recognised that capacity costs vary according to seasonal fluctuations in demand and it was proposed that seasonal peak load rates should be introduced where marginal opportunity costs showed large seasonal variations. Lastly, declining block rate structures were criticised in the face of increasing long-run marginal costs and it was proposed that municipal pricing structures should reflect the "different conditions under which water is consumed".

Gibbs (1978) identified two formulations of the price of water. The second formulation was the marginal or block price defined as the 'price of the last unit of water purchased. He further stated that the use of marginal price in water demand studies was more accurate than the use of average price as the former allowed for analysis of consumer responses to changes in the price structure.

Marginal cost pricing is not widely used amongst the OECD countries (OECD, 1987). The reasons for this are as follows:

- Long-run marginal costs are difficult to determine as they can fluctuate over time and vary according to the time-span over which they are estimated.
- Differentiation between users is difficult resulting in surplus revenue received from some groups and subsidisation of others.
- Charges would vary across regions and are dependent on accurate demand forecasts and investment decisions.

In spite of these shortcomings, many countries have implemented various forms of marginal cost pricing such as increasing block rate tariffs and decreasing block rate tariffs. Herrington, (1980), used 'present worth difference methodology' to determine the marginal cost of wholesale water deliveries in Peru. Hanke (1981) in (OECD, 1987), used a similar method to determine the marginal capital costs of a New York water utility. Both Japan and France have allowed marginal cost pricing to influence tariff design (OECD, 1987).

The Malthusian perspective on resource scarcity predicts absolute physical scarcity in the near future as the resource is depleted this is mainly due to the 'limits to growth' theoretical constraints imposed on an economy. Ricardo however, recognises these limitations but stipulates that markets will react to increasing prices as the resource becomes scarcer and in so doing will encourage resource substitution, efficient use and recycling (Turner et al, 1994). Marginal cost pricing, however, does not account for the shadow price of the resource that in turn reflects the opportunity costs of competing uses for the resource. It implicitly assumes that water is abundant and has an opportunity cost of zero (Hassan, 1997b). Consequently, opportunity cost pricing is regarded as the best pricing approach when attempting to reflect the economic value of water.

3.4.2.5 Opportunity cost pricing

The opportunity cost of water equals the measure of the scarcity value of water to society. Where sectoral differences and interdisciplinary uses are evident, the water should be allocated where the opportunity cost of water is lower than the value of water in the selected use. The opportunity cost of a resource is defined by the World Bank (1993) as, "the value of a good or service forgone, including environmental goods and services. This occurs where a scarce resource is used for a particular purpose and not for its next best alternative use."

Market prices for water may diverge significantly from their shadow (economic opportunity cost) prices due to the existence of distortions such as monopoly practices, external economies and diseconomies, taxes and subsidies (Munsasinghe, 1988). Furthermore, the use of shadow pricing allows the water sector to address social and political goals across sectors and within the water sector itself, that strict efficiency goals overlook (Munasinghe, 1988). For example, a study by Hanke and Davis (1973) indicated that industrial sewerage charges were reported to be much lower than municipal water charges and hence proposed that this price discrimination be corrected by implementing charges that reflected the opportunity costs of pollution.

Irrigation water pricing is of vital importance in arid and semi-arid regions according to (Hamdy et al, 1994), as it has the potential to influence water allocation between competing users, water conservation practices, additional revenue generation, cropping patterns, income distribution, efficiency in water use and various environmental impacts. They propose that water should be regarded as an economic good with an opportunity cost derived from future use expectations.

Algihariani (1994), supports the need for opportunity cost pricing in recognising that where water supplies are subsidised, their prices are lower than their opportunity costs and allocations and uses tend to be inefficient. The role of pricing is further recognised to generate revenue that will cover operation and maintenance costs and must be derived under principles that consider food security, rural incomes and basic needs. Furthermore, property rights among water users must be clearly defined for the correct pricing policy.

In the case of Botswana however, the ability-to-pay principal is still utilised and those who can afford to pay the full cost price of water do so and those who cannot do not. This applies to water consumption for basic needs (Masedi, 1996).

(Hamdy et al, 1994), state that the price of water should include the scarcity value of water and not just cover the direct costs of production, with special attention being paid to pollution, over-exploitation and social aspects of equity.

(Prasad and Rao, 1991) reviewed the pattern of financial returns to irrigation systems in India by focussing on large-scale canal irrigation projects. Finding that the collection costs of water rates approached the revenues realised, providing poor returns on investment. State determined water rates were also much lower than the implicit pricing or shadow prices for water perceived by farmers. In concluding it was proposed that water rates should cover the operation and maintenance costs of water delivery during the initial introduction of water rates.

It is important to determine between the economic costs or benefits foregone in using water in one particular use versus the actual value of water. Monetary values are not easily assigned to the worth of non-consumptive functions. Human life and ecosystem sustainability are considered to be 'priceless' to many and are consequently particularly difficult to value. Consideration needs to be taken of these implications when planning any demand management strategy.

3.4.3 Full cost pricing of water resources

The ultimate goal in pricing strategies is to understand the full-cost of water supply and the full-value of water in use, including the implications for these different prices on different user groups. Rogers et al. (1998) in (Rogers et al., 2001) identify the various levels of water pricing, outlines in figure 3-1. The costs of water reflected in pricing often relate specifically to the costs of supply such as operation and maintenance costs, and capital charges, hence water is under priced. The full economic costs need to be included in these estimates, such as the opportunity costs of water and economic externalities, giving the full economic cost of water. Environmental economic takes this theory one step further and recognises the impacts on the environment not just those on social and economic capital, so environmental externalities also need to be included if one is to reflect the "true" full cost of water supply. The full value of water refers more to the use value of water and incorporates re-use and recycling aspects. The economic values for water are identified below to which intrinsic value is added. Figure 3-1, re-iterates the complexities water managers face when striving to price water so that the full costs and benefits are captured.

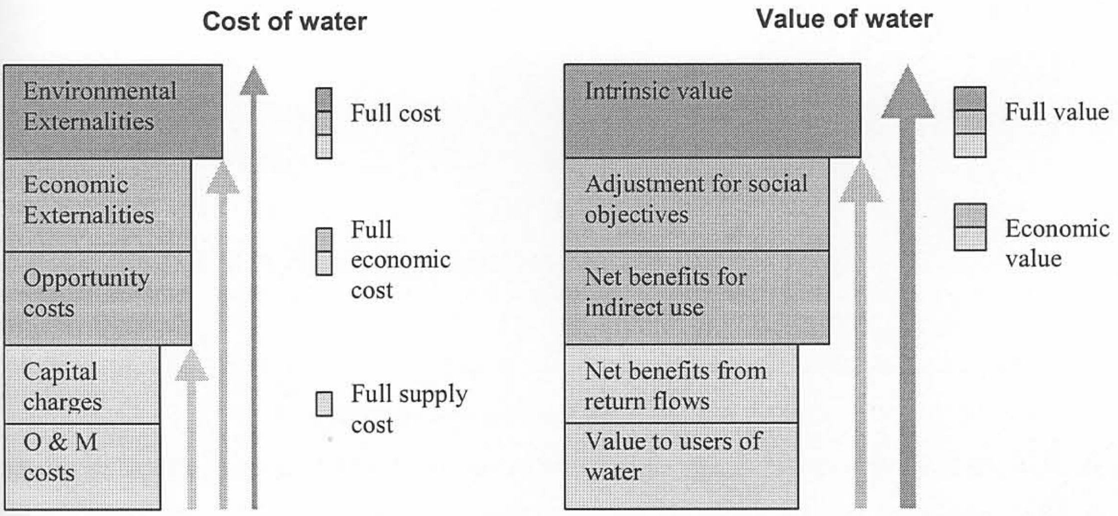


Figure 3-1: Underlying principles for the cost and value of water
Source: Based on Rogers et al., 2001.

3.5 Summary

Markets in tradable water rights are regarded to some extent to be superior to pricing mechanisms as they reduce information costs and may be politically more feasible. By bringing together users with expert knowledge of water use in their respective applications and the productivity values thereof, the market would inherently capture the information costs involved in negotiation further reducing the transaction costs. Where rights to water exist, this process merely formalises these rights and does not necessarily threaten user groups through unplanned price adjustments or hikes (Rosegrant and Binswanger, 1994). Fundamental to the understanding of water markets and pricing strategies is knowledge on the demand and supply of water; the number and type of users; the willingness to engage in market transactions; consensus on prices and price structures; and the nature of demand and the demand curve. The following chapter proceeds to introduce the theory of demand for water and its use in understanding the behavioural consumption patterns of the water consumer.

CHAPTER 4: A REVIEW OF DEMAND THEORY AND ITS APPLICATION TO WATER

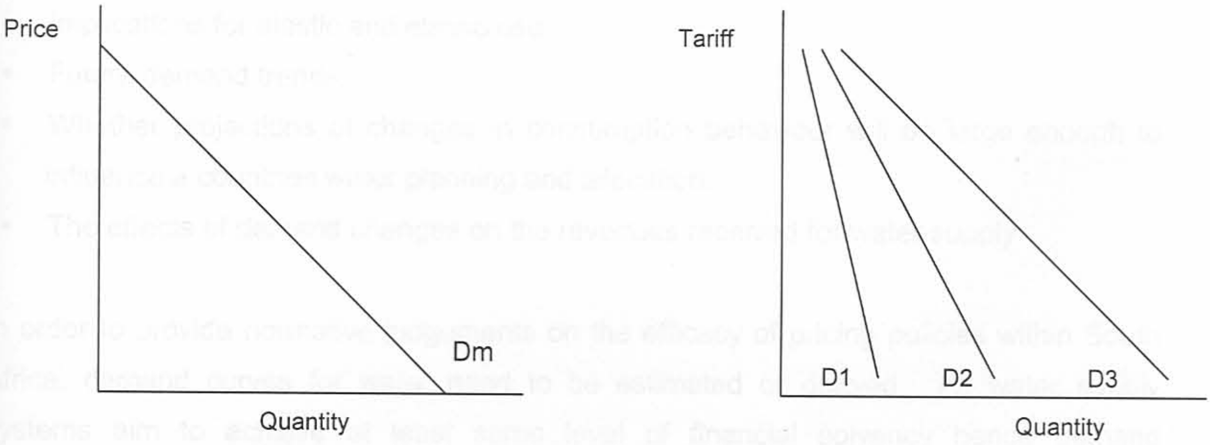
4.1 Introduction

This chapter reviews several methods of demand analysis. The theoretical grounds for various analytical approaches are outlined and compared. Advantages and disadvantages of each approach are discussed and gaps are identified. A limited range of analytical approaches to deriving and estimating demand functions for water have been employed in the literature to map the impacts of price on the quantities demanded of water by various users. Various analytical tools such as elasticities and consumption shares have been used to evaluate the impacts of policy measures on these relationships and the efficacy of water pricing on demand and consumption adjustments. Available models are classified into positive and normative economic approaches. The first approach, positive economics "deals with the objective or scientific explanations of the working of the economy". It is used to provide detailed implications of making a particular choice over another and relies upon the economic mechanisms such as market equilibrium, technology structure and sensitivity analysis. The second approach, normative economics, "offers prescriptions or recommendations based on personal value judgements". It relies on measures of welfare and decision-making based on pareto-optimal criteria (Begg et al, 1991). Conditional normative approaches to economic analysis build on the positive approach by explicitly including optimisation rules and is commonly used in agricultural analysis (Hassan, 1999).

Section 2 of this chapter introduces the concept of demand and its relationship to elasticity. Section 3 outlines the various theoretical approaches to positive demand analysis using market methodologies. Section 4 explains the role of duality in demand theory. Section 5 outlines the pragmatic approaches to econometric estimation of demand for water and section 6 reviews normative approaches to the demand of water. Section 7 outlines the non-economic approaches to demand analysis.

4.2 The water demand curve

Microeconomics is concerned with the explanation and prediction of the economic behaviour of individual units such as consumers, firms and resource owners. It provides an analysis of the relationships between various role players in the market and the factors that influence decision-making. Intrinsic to this process is the understanding of the market and the related workings of its price system (Mansfield, 1994). The demand side of the market may be represented by a market demand schedule that translates into a market demand curve. It represents the quantity of a good that would be purchased at each price. (The market demand curve or aggregate demand curve is the aggregation of a number of different individual demand curves each showing the amount of a particular good that a consumer would purchase at each particular price of that good). The market demand curve represents the level of demand by the market as a whole at each particular market price. Generally, the demand curve represents a negative relationship between price and quantity and the demand curve slopes downwards to the right (as an increase in the income of a particular good leads to a decline in the demand for that particular good). The demand curve also pertains to a particular period in time (a factor which affects the shape and position of the curve), (Mansfield, 1994; Varian, 1996).



Market demand curve

Individual demand curves

Figure 4-1: Hypothetical individual demand curves and market demand curve for water

Source: Own compilation

The distinction between the market demand curve and the individual demand curve is particularly, pertinent when deriving demand curves for water. The actual price of the commodity, water, pertains to the market price whereas the 'tariff' or user charge paid by the consumer pertains to the individual demand curve (figure 4-1).

When relating the price of a commodity or group of commodities to the quantity demanded by consumers or purchasers, the economic concept of demand hinges on a strict set of assumptions implying that the following factors are held constant (Mansfield, 1991, Varian, 1996, Dockel et al, 1979, Begg et al, 1991):

- The prices of other commodities;
- Consumers' incomes;
- Consumption preferences and tastes;
- Consumers' future expectations;
- The number of consumers.

Resource demand such as that for water is also dependent upon other variables such as the nature of the demand for the product, the supply of other inputs, the degree of substitutability between inputs, the time-period of adjustment and the existing market structure (Shumway, 1973). Demand curves play an intrinsic role in economic theory and provide various applications for practical analysis (Dockel et al, 1979). Knowledge of the demand for water by various user groups can be used to determine some of the following:

- The influence of gradual price increases on the level of demand.
- The levels of responsiveness of different user groups to the changes in price.
- Implications for elastic and elastic use.
- Future demand trends.
- Whether projections of changes in consumption behaviour will be large enough to influence a countries water planning and allocation.
- The effects of demand changes on the revenues received for water supply

In order to provide normative judgements on the efficacy of pricing policies within South Africa, demand curves for water need to be estimated or derived. All water supply systems aim to achieve at least some level of financial solvency hence demand projections are necessary. In turn, the determining factors of this demand must be measured. One measure important to projection analysis is that of elasticity (both income and price). Indicating the percentage by which demand changes with changes in income and price respectively, elasticities for 'necessities', such as water, are expected to lie between zero and one (Katzman, 1977).

Theoretical demand represents the relationship between the price and quantity of a particular good while holding all other things constant. It is derived from the underlying preferences of a consumer and maps the optimal amounts of each of the chosen goods as a function of prices and income faced by the consumer during the decision-making process, such that,

$$x_i = x_i\left(p_1 , p_2 , m\right) \tag{4-1}$$

$$x_2 = x_2\left(p_1 , p_2 , m\right) \tag{4-2}$$

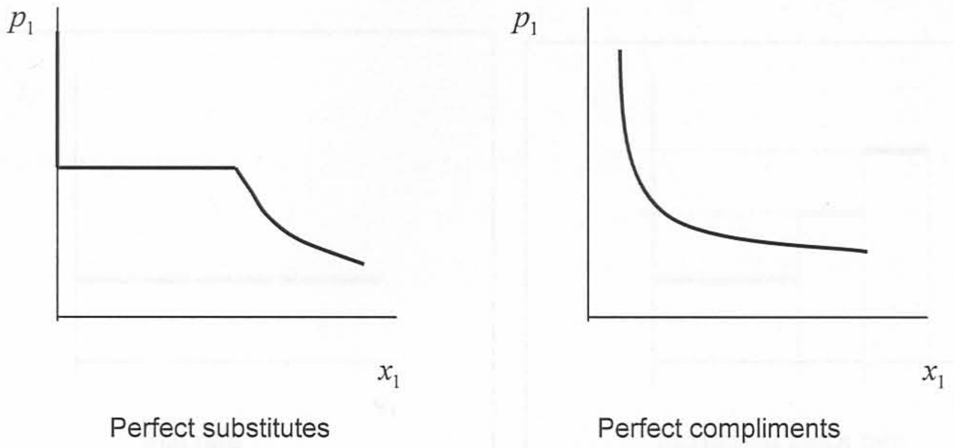
where, x_1 and x_2 are the quantity demanded of good 1 and good 2 respectively; p_1 and p_2 are the prices of good 1 and good 2 respectively; m is household income. The demand curve for x_1 assumes that the price of good 2 (p_2) and income (m) are held constant and the demand curve for x_2 assumes that the price of good 1 (p_1) and income (m) are held constant.

Typically, as the price of a good increases, the demand for that good decreases, provided other influencing factors such as income remain constant, hence, price and quantity tend to move in opposite directions and the demand curve slopes downward such that,

$$\frac{\Delta x_1}{\Delta p_1} < 0 \tag{4-3}$$

Only in the exceptional case of giffon goods will demand increase as price increases (Begg, 1991; Varian, 1996).

For goods that have a high degree of substitutability and there are alternatives available, the price of these alternatives will impact the demand for the original good. If the alternative good is a substitute then the demand for the original good, say (x_1) will increase if $p_1 < p_2$ to ${}^{m}\!/_{p_1}$; remain the same or change to any random quantity if $p_1 = p_2$ and decrease towards zero when $p_1 > p_2$. For perfect complements there exists a combination of goods that a consumer is encouraged to consume together, such that the quantities demanded of both goods will change in the same way depending on the price changes, irrespective of whether the prices are the same or different (Varian, 1996). Figure 4-2 depicts the demand curves for substitutes and for compliments.



Perfect substitutes Perfect compliments

Figure 4-2: Demand curves dependent on the price of relative goods

Source: Varian, 1996

The second factor that impacts the level of demand is consumer income. Assuming prices remain fixed, one can compare optimal choices at different levels of income. Normal goods are defined as goods, the demand for which increases as income rises, conversely inferior goods are goods for which demand decreases as income rises. Normal goods are further classified into luxury and necessary items, dependent on the proportionate change to income. Should the demand for a good increase by more than the increase in income, it is a luxury but where the increase in demand is less than the increase in income the good is a necessity (Begg, 1991; Varian, 1996).

As mentioned in previous chapters, water is regarded as a normal good and a necessity. The degree of substitutability of water with other products is relatively negligible for most uses, unless technology is greatly revised, for example a shift in electricity generation from hydroelectric power to other forms. The purpose of this study is to determine the demand for domestic water use and this incorporates life support uses for which there are no substitutes. Hence, measures such as the cross-price elasticity of demand will not be determined. Figure 4-3 depicts various demand curves that may result from the different tariff structures for water outlined in chapter 6.

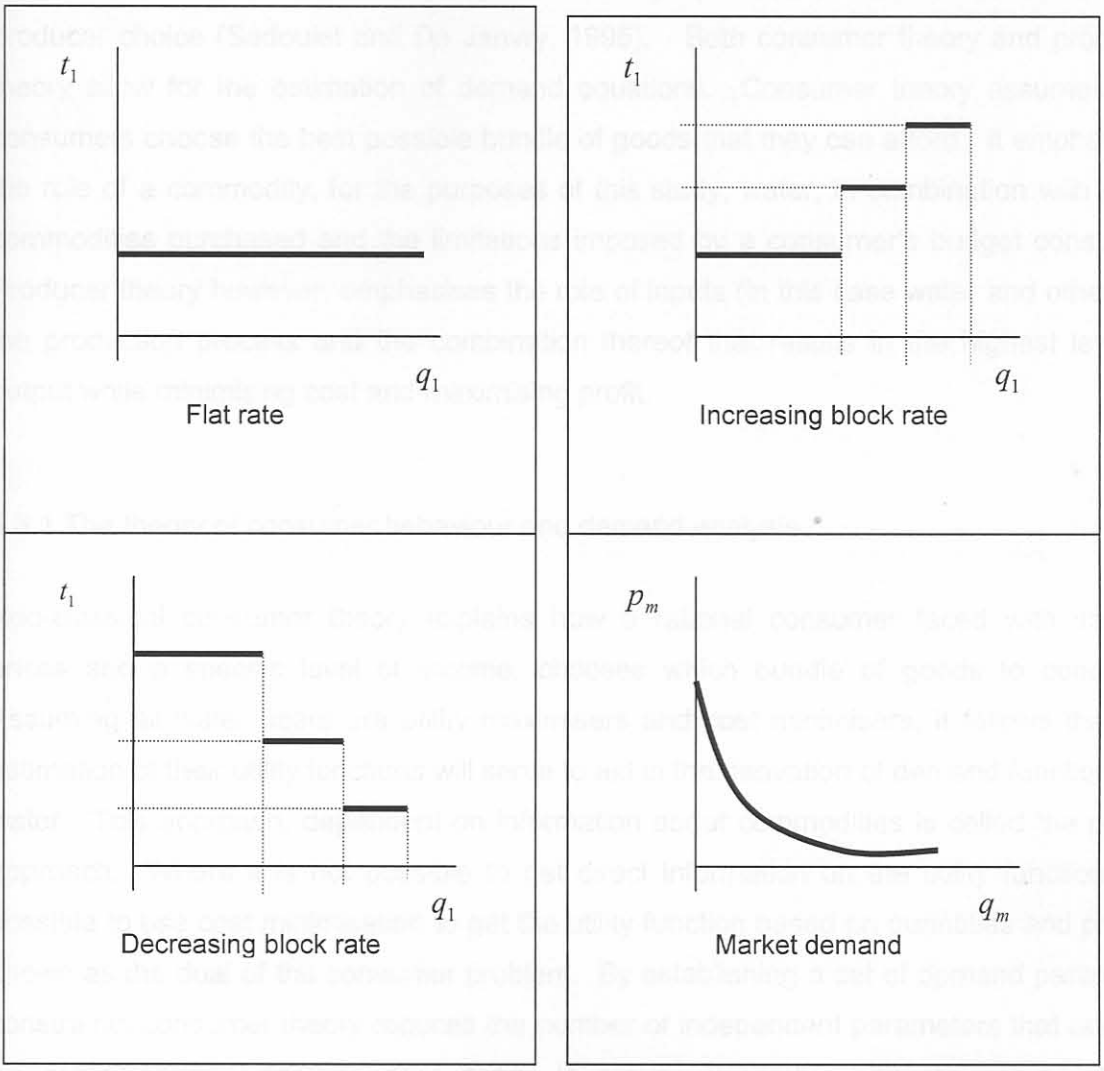


Figure 4-3: Hypothetical demand curves based on water tariff structures

Source: Own graphical representation

For a further discussion on these pricing structures, see section 3.4.2.2 on delivery cost pricing. The market demand curve depicted here is a hypothetical aggregate of demand for the various structures based on the flat rate and decreasing block rate scenarios.

4.3 Theoretical approaches to positive demand analysis

The theoretical approach to the estimation of demand equation parameters relies on the theory of demand to guide the choice of functional form and the inclusion of the relevant variables. This approach proves to be valuable in its ability to impose constraints on the demand parameters thereby reducing the need to estimate unnecessary independent parameters where limitations on available data exist. It also ensures that the estimated demand equations are based on mathematically specified models of consumer and producer choice (Sadoulet and De Janvry, 1995). Both consumer theory and producer theory allow for the estimation of demand equations. Consumer theory assumes that consumers choose the best possible bundle of goods that they can afford. It emphasises the role of a commodity, for the purposes of this study, water, in combination with other commodities purchased and the limitations imposed by a consumer's budget constraint. Producer theory however, emphasises the role of inputs (in this case water and others) in the production process and the combination thereof that results in the highest level of output while minimising cost and maximising profit.

4.3.1 The theory of consumer behaviour and demand analysis

Neo-classical consumer theory explains how a rational consumer faced with various prices and a specific level of income, chooses which bundle of goods to consume. Assuming all water users are utility maximisers and cost minimisers, it follows that the estimation of their utility functions will serve to aid in the derivation of demand functions for water. This approach, dependent on information about commodities is called the primal approach. Where it is not possible to get direct information on the utility function it is possible to use cost minimisation to get the utility function based on quantities and prices, known as the dual of the consumer problem. By establishing a set of demand parameter constraints consumer theory reduces the number of independent parameters that need to be estimated and ensures consistency in results (Sadoulet and De Janvry, 1995; Mansfield, 1991; Varian, 1996). Intrinsic to the estimation of demand curves based on consumer theory are utility, engel curves and consumer cost minimisation.

4.3.1.1 Utility

Economics has defined utility as a measure of a person's well-being or happiness, this unit is however extremely difficult to measure or compare conceptually and has therefore been reformulated in terms of a consumers preferences, described by the concept of utility, figure 4-4.

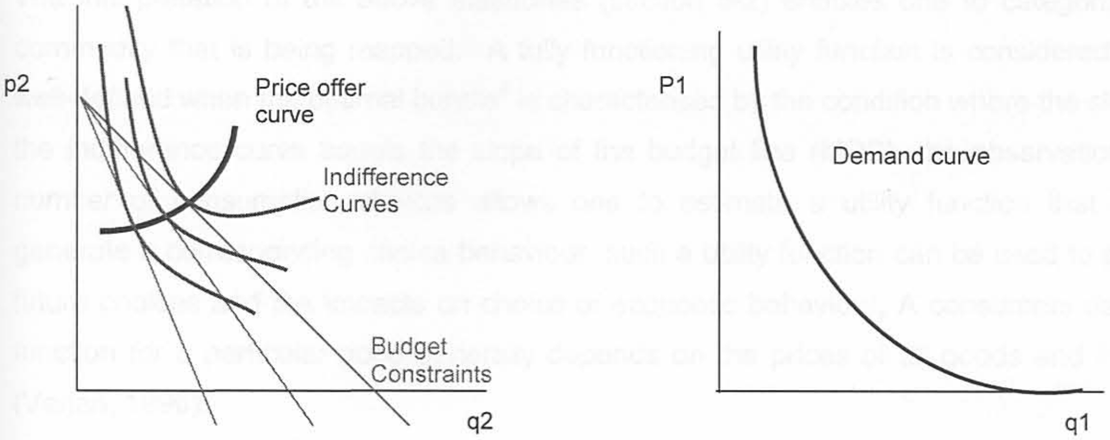


Figure 4-4: Utility and demand

Source: Sadoulet and De Janvry, 1995

The utility maximization problem, assumes that an individual consumer is faced with an utility function subject to some budget constraint,

$$U = v(q, z) \tag{4-4}$$

subject to

$$m = p * q \tag{4-5}$$

using the Lagrange multiplier, the constrained optimisation problem is,

$$U_{\max} = v(q, z) - \lambda(m - p * q) \tag{4-6}$$

solving the above equation using first order conditions, generates a set of Marshallian demand functions,

$$qi = qi(m, p, z), \quad for\ all\ i = 1, \dots, n. \tag{4-7}$$

From the above demand function, income and price elasticities of demand can be obtained as follows,

$$\eta_i = \frac{\partial q_i}{\partial m} * \frac{m}{q_i} \quad \text{- income elasticity} \tag{4-8}$$

$$e_{ii} = \frac{\partial q_i}{\partial p_i} * \frac{p_i}{q_i} = \frac{MU}{AU} \quad \text{- price elasticity} \tag{4-9}$$

The interpretation of the above elasticities (section 5-2) enables one to categorise the commodity that is being mapped. A fully functioning utility function is considered to be well-defined when the optimal bundle[6] is characterised by the condition where the slope of the indifference curve equals the slope of the budget line (MRS), the observation of a number of consumption choices allows one to estimate a utility function that would generate a corresponding choice behaviour, such a utility function can be used to predict future choices and the impacts on choice of economic behaviour, A consumers demand function for a particular good generally depends on the prices of all goods and income (Varian, 1996).

For the purposes of empirical estimation, time series water data is required for the utility function. Clear observations of price changes over a reasonable time span allow for the estimation of the respective price elasticities.

4.3.1.2 Engel curves

An optimal choice of goods exists at each level of income. For example, the optimal choice of good (x1) can be written as x_1 (p_1, p_2, m), the demand function for good 1. If the prices of the goods, p_1 and p_2 are held constant and the impacts of demand are observed due to changes in income, m, then an Engel curve is generated. An Engel curve represents demand for water as a function of income and constant prices (Varian, 1996).

The Engel curve takes the mathematical form,

$$qi \quad = \quad qi\,(m\,,\,z), \qquad for\ all\ i = 1,\ldots,n. \tag{4-10}$$

where, m denotes income and z denotes characteristics that vary across households, including family size, geographical location, age and education. The Engel curve may take any functional form[7] but the semi-logarithmic tends to perform the best under empirical analysis (Sadoulet and De Janvry, 1995). A fully functioning engel curve exists when the budget constraint is satisfied so that total expenditure and predicted expenditure for each commodity should be equal; all forms of goods such as luxuries, necessities and inferior goods may be represented as well as variable income elasticities; as income

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[6] the optimal choice of the consumer is that bundle in the consumer's budget set that lies on the highest indifference curve.

[7] See appendix 3 for a description of the functional forms

increases a saturation point in consumption of commodities should occur. From the above equation, it is possible to determine income elasticities. The price elasticities are however more difficult to determine as they intrinsically require some observation of demand changes for water under various price conditions. One approach to estimating price elasticities of demand from cross-sectional household expenditure survey data with spatial variations in prices is to 'cluster' households with access to the same markets, thereby isolating price changes to location specific variables or transactions. Using expenditure and quantity data it is then possible to calculate the unit values and expenditure shares for each household. From these, price elasticities of demand may be directly estimated,

$$\frac{y_i}{q_i} = v_i, \qquad \frac{y_i}{y} = w_i \tag{4-11}$$

The shortcoming of the above approach is that it tends to overestimate the true price elasticity of demand (Sadoulet and De Janvry, 1995).

Where no information on the observations of price variations is available, but household budget surveys yield cross-sectional data, it is possible to estimate an Engel curve for water instead of a utility function, in order to get demand. Data on income, other household variables and levels of demand are required (Sadoulet and De Janvry, 1995).

4.3.1.3 Cost minimisation

In (section 4.3.1) the consumers' problem was formulated as maximising utility for a given outlay or cost, giving a solution of some utility level, u. This problem can however be reformulated to find the amount of goods that would minimise the cost of producing some level of utility, u. This approach is referred to as the dual of consumer choice (Deaton et al., 1980).

Consider the original problem,

$$Maximise\ U = v(q) \tag{4-12}$$

Subject to,

$$x = \sum p_i \, q_i \tag{4-13}$$

Which generates a solution set of Marshallian demands,

$$q_i = g_i\left(x\,,p\right) \tag{4-14}$$

The dual of the cost problem however considers some expenditure function,

$$Minimise\ x = \sum p_i \, q_i \tag{4-15}$$

Subject to some level of utility,

$$v\left(q\right) = U \tag{4-16}$$

that in turn yields a set of cost-minimising demand functions dependent not on prices and costs, but on prices and a fixed level of utility, commonly referred to as the Hicksian or compensated demand functions, as they show us how quantity demanded changes when prices change and utility is held constant,

$$q_i = h_i\left(u\,,p\right) \tag{4-17}$$

From the above set of Marshallian demand functions and Hicksian demand functions, partial derivatives may be obtained,

$$f'\left(q_i\right) = \frac{\partial\, q_i}{\partial\, p_i} = MP \tag{4-18}$$

$$f'\left(qi\right) * AP = \frac{\partial\, qi}{\partial\, pi} * \frac{pi}{qi} = \frac{MP}{AP} \tag{4-19}$$

As the Marshallian and Hicksian demand functions coincide, they may be substituted back into their respective original functions to determine the maximum utility and the minimum cost that can possibly be obtained,

$$\begin{aligned} U &= v\left(q_1, q_2, \ldots, q_n\right) = v\left[g_i\left(x, p\right), \ldots, g_n\left(x, p\right)\right] \\ &= \psi\left(x, p\right) \qquad (4\text{-}20) \\ &= \text{maximum utility} \end{aligned}$$

$$x = \Sigma\, p_x\, h_x\left(u, p\right) = c\left(u, p\right) = \text{minimum cost} \qquad (4\text{-}21)$$

The above formulations may be rewritten as follows,

$$\psi\left(x, p\right) = \max_q\left[v\left(q\right); \Sigma\, p * q = x\right] \quad - \textit{indirect utility function} \qquad (4\text{-}22)$$

$$c\left(u, p\right) = \min q\left[\Sigma\, p\, q\, ; v(q) = U\right] \quad - \text{cos}\,t \;\; \textit{function} \qquad (4\text{-}23)$$

Interestingly, the dual of the utility and cost functions can be used to formulate different procedures that ultimately determine the underlying Hicksian and Marshallian demand functions. First, it is possible to begin with a cost function specified in terms of utility and prices. Taking the derivative thereof, according to Shephard's Lemma, yields the Hicksian demand, h_i (u, p) = q_i . Second, by substituting the maximising level of utility back into the Hicksian demand function, it is possible to derive Marshallian demands, q_i [u(x, p); p] = g_i (x, p). Third, taking the derivative of the indirect utility function and applying Shephard's lemma, will yield Marshallian demands,

$$q_i = q_i\left(x, p\right) = \frac{-\partial\psi \big/ \partial p_i}{\partial\psi \big/ \partial x} \qquad (4\text{-}24)$$

In a similar way, revealed and stated preferences can be used to determine hicksian and marshallian demand functions, discussed in section 4.7, where data on prices and quantities demanded for water are not specifically observable. These can be further used to determine compensating variation, equivalent variation and consumer surplus welfare measures.

The utility-based cost function is fully functioning when it is homogenous of degree one in prices and for a scalar $\phi > 0$. Therefore as prices double, the expenditure required to remain on the same indifference curve also doubles, $c\,(u, \phi\, p) = \phi\, c\,(u, p)$; increasing in utility, u; non-decreasing in prices, p and increasing in at least one price; concave in prices for all forms of indifference curves, implying that costs will rise linearly as prices increase. For a review of this proof see (Deaton et al., 1980); continuous in prices, p, and is twice differentiable; and taking the first partial derivative of the utility based cost function yields the Hicksian demand functions, otherwise known as Shephard's Lemma (Deaton et al, 1980; Sadoulet et al, 1989; Hassan, 1999):

$$\frac{\partial c\,(u\,,p)}{\partial\, p_i} \equiv h_i\,(u\,,p) = q_i$$

Estimations of the utility-based cost function require data on utility and prices. The former is however particularly difficult to obtain as it is based in the theoretical bounds of economics and is limited in its practical empirical application. The derived demand based on the utility-cost function can however be explained through theoretical derivations and requires data on the prices and quantities of the respective good.

4.3.1.4 Multi-output demand equations

Individual demand modelling discussed above allows for the variation of functional form and for the addition or removal of explanatory variables at any researcher's discretion. Individual demand modelling is highly flexible but adheres more closely to the pragmatic approach, as the only theoretical restriction that really provides value is that of homogeneity. Theory however, becomes far more relevant for complete demand estimation or demand systems estimation and a greater range of restrictions may be applied (Deaton et al, 1980).

The choice of demand system is important as this choice holds certain consequences for the estimated parameters. Evidently, demand systems derived from additive utility functions such as the Linear Expenditure System (LES) or the Generalised Linear Expenditure System (GLES) tend to have own-price elasticities proportional to the income elasticities, while the Almost Ideal Demand System (AIDS) does not (Mergos and Donatos, 1972).

The LES is based on the Stone-Geary utility function of the form,

$$U = \Sigma_i\, b_i \ln\left(q_i - c_i\right) \qquad (4\text{-}25)$$

Where ci is the "committed" or minimum subsistence of consumption. Through utility maximisation the following demand curves are obtained,

$$p_i\, q_i \;=\; c_i\, p_i \;+\; b_i\left(Y - \Sigma_j\, c_j\, p_j\right) \qquad \text{for all } i, j = 1, 2, \ldots, n \tag{4-26}$$

$\Sigma c_i p_i$ is the subsistence expenditure and the term (y - $\Sigma c_j p_j$) is generally interpreted as "uncommitted" or "supernumerary" income which is spent in fixed proportions b_i between the commodities.

These n equations generate the following price and income elasticities

$$E_{ii} = -1 + \left(1 - b_i\right)\frac{c_i}{q_i}, \tag{4-27}$$

$$E_{ij} = -\frac{b_i c_j p_j}{p_i q_i}, \tag{4-28}$$

$$\eta_i = \frac{b_i}{w_i} \tag{4-29}$$

From the above demand curves it is evident that data on the prices of the goods consumed as well as expenditure for a household is required for estimation. The almost ideal demand system (AIDS) is however, based on the budget share and its role in utility maximisation and hence requires data on the shares of a households budget that are spent on consuming certain goods, along with the prices of these goods and the quantities consumed. Both may be used to estimate the demand for household water use, although the estimations would require extensive surveying as much of this information is not readily available, hence this approach is not followed in this study.

4.3.2 The theory of producer behaviour and demand analysis

Another approach to estimating the demand for water is based on the theory of producer behaviour. This is based on the premise that water may be considered as one of the inputs into the production process that in turn generates some level of output and one can determine the factor demand of the input in terms of quantities of inputs and outputs or in terms of prices and quantities of inputs. This approach is not applicable to the estimation of residential water demand as households are utility maximisers and not profit maximisers. The approach is however, reviewed here as it defines an invaluable approach to the estimation of demand theory. Furthermore, the Tshwane study includes the estimation of demand for industrial users using the pragmatic approach, and it is interesting to provide the theoretical framework that could otherwise be applied to this kind of demand estimation.

4.3.2.1 Production functions and the related profit and cost functions

The production function is based on the assumption that a relationship exists between inputs and outputs, it measures the maximum level of output that can be obtained from a given vector of inputs (Chambers, 1988; Coelli et al, 1998; Varian, 1996). The function is single valued so that for any combination of inputs, only one value of output may be obtained, such that,

$$Y = f(x_1, x_2) \tag{4-30}$$

This function merely represents a technical relationship that aims to exclude any technical inefficiencies. For the modelling of water as an input into the production process, quantities of water are used as one of the inputs on the right-hand side of the equation above.

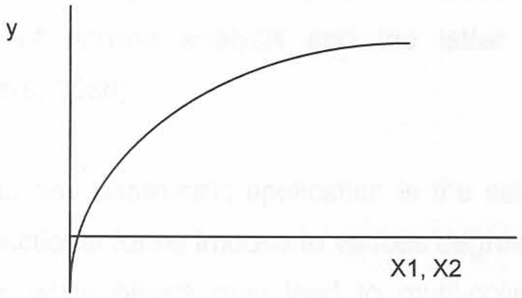

Figure 4-5: A simple production function

A fully-functioning production function is assumed to be twice continuously differentiable, therefore the first and second derivatives are continuous and can both be differentiated. By implication the second cross partials are symmetric and equal each other,

$\frac{\partial^2 Y}{\partial X_1 \partial X_2} = \frac{\partial^2 Y}{\partial X_2 \partial X_1}$; strictly increasing in x, implying monotonicity[3], positive marginal products and concavity; inputs are non-zero for any level of output; the production of

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[3] Monotonicity implies that the function does not decrease.

inputs is feasible so their sets must be closed and non-empty; and the function is finite, non-negative and real valued for all values of x and y.

Although the above properties of the production function are adequate for theoretical production function analysis, they are not restrictive enough for strictly applied quantitative analysis or empirical tractability. As most entrepreneurial bodies remain relatively unmoved by the theoretical dictates that price rises should lead to greater output supplied, they will however be more interested in the specifics as to the quantitative amounts by which this output should change in accordance to various price level changes. Consequently, the more restrictive assumptions such as homotheticity and seperability impose structural constraints on the production function that facilitate applied economic analysis.

Production functions may be estimated provided information on input and output quantities is available. This may be done using sample data (Chambers, 1988). The sample data may be in the form of cross-sectional data (involving a number of observations within a particular time period), time-series-data (aggregate data observed over a number of time periods), or panel data (a number of observations made over a number of time periods). Both parametric (econometric methods) and non-parametric (mathematical programming) production functions have been estimated, the former for the purpose of applied analysis and the latter for the purpose of efficiency analysis (Chambers, 1988).

Implicit to any parametric application is the selection of an appropriate functional form. Some functional forms impose to various degrees, restrictive properties on the production structure, while others may lead to multi-collinearity and limited degrees of freedom problems (Chambers, 1988). The most commonly used functional forms for the estimation of production functions are the Leontief and Cobb-Douglas functions.

Water plays a pivotal role in modern agriculture therefore there exists a need to determine the optimal use of water and land resources including the improvement of water management systems through the understanding of the efficiency of production systems (De Juan et al, 1996). In order to solve the problem of optimal water management on farms, information and knowledge on the water consumption of each crop, crop responses to irrigation, agro-climatic data and their effects on crops, and maximum crop evapotranspiration, all of which can be combined in crop production functions for water. From the above it is evident that a production function for water may be applied to any relationship that characterises a crops response to different input combinations such as water, fertilisers, energy, crop-yield and the seasonal amount of applied water (Letey et al, 1985).

Water production functions are usually only valid for a single crop at a single location under conditions of "optimal deficit sequence". They often exclude information on the environmental impacts of irrigation and energy saving. Rao et al (1988) developed a two-stage model that incorporated the above variables and estimated a functional relationship between crop yield and water use. A dated water-production function model was also derived from crop growth stage yield response factors, deducing that a simple heuristic form is applicable over a multitude of stress conditions that can be used where data on crop yield and water use is poor. Letey et al (1985) also recognised that profit maximising conditions were useful as a means of determining the efficient allocation of resources such as water and compared the yields of tall fescue to variations in water salinity and the quantity of irrigation water. The results showed that as water was applied the yield increased to a point beyond which it plateaued, the results were however limited by the specification of the original parameters, see figure 4-6 below.

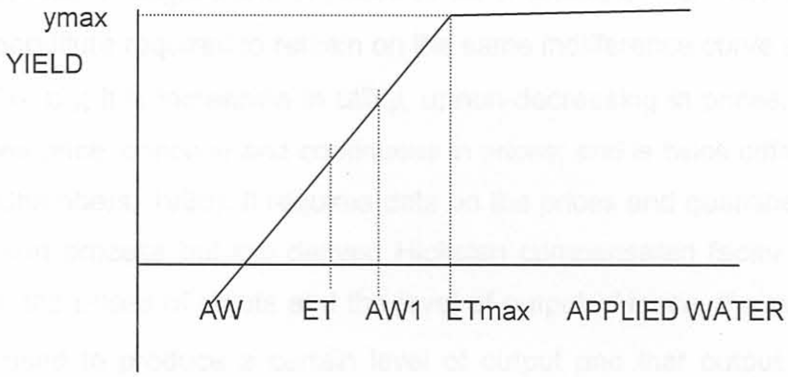

Figure 4-6: Relationship between yield and seasonal applied non-saline water

Source: Letey et al, 1985

Most studies on water production functions emphasise the use of production functions in order to optimise the application of irrigation water (Letey et al, 1985; Sharma and Alonso Neto, 1986; Rajput and Singh, 1986; Russo and Bakker, 1987; Rao et al, 1988; and De Juan et al, 1996). The literature so far, reveals that the production function approach is not used for estimating residential or household water demand and furthermore none of the irrigation based production functions used to derive the demand for water continue further to derive price or income elasticities for water demand.

Three other approaches underlying producer theory are those of profit maximisation and cost minimisation and the revenue function. All three approaches were reviewed for this study but specific studies relating these approaches to water resources were not evident. Only cost functions for service provision could be identified (discussed below). Basically, a well-functioning profit function for water is characterised by positive profits, such that $\Pi (p, w) \geq 0$. Prices are non-decreasing, such that if $p1 \geq p2$, then $\Pi (p1, w) \geq \Pi (p2, w)$ and costs are non-increasing such that if $w1 \geq w2$, then $\Pi (p, w1) \geq \Pi (p, w2)$. The profit function, $\Pi (p, w)$, is convex and continuous in p and w and displays the characteristics of positive linear homogeneity, such that, $\Pi (tp, tw) = t \Pi (p, w)$, where $t > 0$. Estimation of the profit function requires data on the output prices that producers accept as given, the quantity of a good produced, the cost of various inputs used, and the input prices that producers accept as given. All costs of production must be included in the calculation of costs and everything must be measured on a compatible time scale. No studies relating the profit function approach to estimating the demand for water could be found.

The cost function however, represents the "minimum cost of producing a given output level during a given time period expressed as a function of input prices and output", and is homogenous of degree one in prices or for a scalar, $\phi > 0$. Therefore as prices double, the expenditure required to remain on the same indifference curve also doubles, $c(u, \phi p) = \phi c (u, p)$; it is increasing in utility, u; non-decreasing in prices, p and increasing in at least one price; concave and continuous in prices; and is twice differentiable (Binswanger, 1974; Chambers, 1988). It requires data on the prices and quantities of inputs used in the production process but the derived Hicksian compensated factor demand only requires data on the prices of inputs and the level of output. Hence, the price of water and other inputs used to produce a certain level of output and that output $\overline{Q}$. Firestone (1982) developed a statistical cost function on water mains for the Melbourne Metropolitan Board based on economies of scale. The study did not however estimate derived demand functions for water but determined the average and marginal cost options for different supply schemes. The determination of elasticities from cost derived demands does not appear to have been used as an approach for water demand.

Interestingly, the role of duality allows the primal formulation of an economic problem whether cost, profit, revenue, or production optimisation, to be adjusted in terms of dependent variables and rewritten in a different formulation (Sadoulet and De Janvry, 1995). Where a chosen function yields explicit demands, the demand equations are particularly simple to obtain although they require relatively complex algebraic solutions.

However, one can still obtain the derived demand functions for any functional form through the application of five theorems commonly used in duality, namely, Hotelling's Theorem 1 or otherwise known as Shephards Lemma; Shephard's Theorem; Roy's Theorem; World's Theorem and Hotelling's Theorem 2 (Pope, 1982). Duality is measured by a number of successes and failures, they are noted below Pope, 1982).

- Both duals and primals may be used to test structural properties such as: returns to scale, homotheticity, separability, structural change, homogeneity, and other characteristics.
- For some functional forms, solving for first-order conditions does not yield input demands and output supplies, by using Hotelling's theorems, it is possible to obtain the duals from which reduced form input demands and product supplies may be derived.
- Primal systems estimations may be limited by their ability to handle effectively Leontief technologies and estimations when input demands are more co-linear than prices. Duality is able to address these shortfalls of the primal approach.
- Simple estimation methods may be used as duality yields explicit reduced forms where prices are independent.
- The dual approach is easier to use when solving for the welfare impacts of an economic environment.
- Duality is limited in cases where prices are co-linear, such as for intra-seasonal prices of an input (water or fertilisers). In such cases the primal problem will recover the underlying technology more comprehensively.
- Duality is further limited by poorly defined underlying theoretical restrictions or in cases where they are not clearly satisfied, such as where the objective function is non-linear in parameters. For these cases, duality is not an effective approach.

For the purposes of household water demand estimation in this study, the role of duality does not specifically apply as the pragmatic approach is followed. The dual approach based on producer or consumer theory is not applied.

4.4 Pragmatic approaches to positive demand analysis

The pragmatic approach to estimating single equation demand functions relies on the intuition and common sense of the economist facilitating the estimation process. It does not refer to the underlying economic theory for guidance in the selection of the most appropriate functional form or the relevant variables to be included in the model. Although proving to be an attractively simple approach to demand estimation, the pragmatic approach is limited by some serious shortcomings. First, the arbitrary selection of the functional forms for the demand equations and the variables to be included may raise doubt as to the ability of the estimated equation to accurately represent consumer or producer behaviour as well as the underlying behavioural assumptions. Second, the inappropriate choice of functional form may result in the incorrect derivation of the underlying technology structure. For example, for the cobb-douglas functional form, elasticities will be constant over all values of the exogenous variables. They may however vary in reality with long-run price adjustments. Third, the estimated parameters are unlikely to satisfy the restrictions imposed on them by demand theory (Sadoulet and De Janvry, 1995).

Despite these shortcomings, the majority of studies directed at estimating demand functions for water rely on this approach. A pragmatic model usually takes the following form:

$$Q_i \quad = \quad f\left(P_i\,,P_j\,,z\right) \qquad \text{(4-31)}$$

Where the quantity of the good (Q_i) is dependent on any selection of independent variables that usually include the price of the good itself (P_i), various other price variables (P_j), and other socio-economic variables (z) that appropriately explain its behaviour.

4.4.1 Application of the pragmatic approach to estimating demand curves for water

The modelling of water demand plays an important role in the planning and management of water resources for urban, industrial and agricultural use (Miaou, 1990a,b). Numerous demand models for urban water use have been proposed based on neo-classical consumer theory and solved by means of linear regression. However, common problems with model specifications have been apparent. First, the length of time for which data is available is usually too short, rendering the degrees of freedom particularly low for any statistical testing. Second, the collected set of explanatory variables must be especially large if it is to be representative. It needs to include socio-economic, environmental, technological and other valid 'input' variables. Third, socio-economic and climatic input variables are often highly correlated, this multicollinearity may adversely affect the statistical validity of results. Fourth, the error terms in models may be autocorrelated or non-stationary (Miaou, 1990a,b).

In (section 5-3), some of the demand models for residential water demand are reviewed and critically discussed. The analysis emphasises the extent to which demand models based on the pragmatic approach differ and hence re-iterates the need for caution when interpreting the results.

4.4.2 Data requirements for the pragmatic approach

The pragmatic estimation of demand models may include variables based on any available data. Cross-sectional and time-series data may be used that include a wide variety of exogenous variables. For the purposes of water demand estimation any combination of the following exogenous variables may be included: water price (marginal or average); household income; number of persons per household; irrigable lawn area; the market value of the home; household water consumption; age of dwelling unit; average water pressure; sum of water and sewerage charges; number of billing periods; regional price index; temperature; precipitation; number of rainy days; soil moisture content; evapotranspiration; number of water dependent household appliances, such as dishwashers and washing machines; number of water saving devices; swimming pools; and mandatory restrictions. Household estimations, however, rely on household specific data that is often tedious and difficult to collect.

4.5 Normative demand analysis

In contrast to the various aspects of positive economics discussed above that aim to provide objective or scientific explanations on how society and firms make decisions, normative economics ‘offers prescriptions or recommendations based on personal value judgements’, and not distinctions between whether these judgements are right or wrong (Begg et. al, 1991). The normative approach requires the estimation of technology parameters as done in the positive approach. These parameters are then used in mathematical programming in order to find optimal solutions in terms of choices or constraints. The normative approach is valuable in its ability to answer normative questions based on non-historic data, it also becomes valuable when valuing natural resources as the programming solutions can generate marginal or shadow prices for the respective resource in question. The approach is however, limited by its ability to fully account for aggregations, technical changes, dynamics and realistic specifications of the problem (Hassan, 1998). The normative approach allows data to be produced through the techniques of parametric programming. Available data on any of the variables that could impact certain decision-making processes can be included. The models are usually based on time-series data.

4.6 Non-economic approaches to demand analysis

Where an econometric approach to demand analysis is hampered by poor databases for endogenous and exogenous variables including prices and quantities for water demanded, non-economic approaches may be used for estimation. Two approaches exist that may be used to estimate a household or individuals 'willingness to pay' for a particular good or service. The first approach is the contingent valuation method (CVM), from which the demand for water and related price elasticities may be estimated. The CVM approach uses surveys to collect data on household decisions. Households or individuals are asked directly to state how much they would be willing to pay in order to have or maintain a particular good or service. Where the changes in prices are to be evaluated, they may also be asked to state by how much their demand would change should the price of a good or service shift up or down. Although critics of CVM claim that it does not yield reliable results due to strategic bias', gamesmanship, and interviewer influence, it is often used in the field of environmental economics to determine the value of environmental goods and services that do not have market prices, such as rural water (Thomas and Syme, 1988; Whittington et al., 1990; Piper et al., 1997; North and Griffin, 1993).

Thomas and Syme, (1988) used this approach to estimate water demand for the Perth Metropolitan Area, Australia due to a lack of sufficient data for empirical estimations. The questionnaire was administered to 312 households selected from a sample frame of 3300 households. The results indicated that the elasticity of demand with respect to a price increase was –0.2. This low elasticity result was attributed to various aspects such as: households having access to private boreholes or wells, low consumer profiles, high income groups and a few consumers indicating that water was not important to their lifestyles. In-house water use had lower elasticities than outdoor water use, results consistent with economic demand theory. The study suggested that the CVM approach proved to be a valuable tool for elucidating price responses where inadequate time series data was a hindrance. This study did however have the advantage of a substantial database gained from previous surveys.

The user's willingness to pay for facilities and resources often determines the success of water or sanitation supply schemes, hence, Rogerson, (1996), undertook an overview of international literature on 'willingness to pay' research. The findings indicated that relatively few studies have been undertaken on 'willingness to pay' for water services, most of which have been linked to the World Bank and other development agencies. Surveys on water-vending services in developing counties were shown to provide valuable sources of information for water resource planning. Furthermore contingent valuation surveys were shown to disclose useful information on consumer / household preferences despite being criticised as "not truly participatory" and "reliant on external resources to generate information on household's willingness to pay", [Dzikus and Surjadi, (1995), in Rogerson, (1996)]. Consequently, contingent valuation surveys were suggested as useful tools for data collection on willingness to pay especially in developing countries such as South Africa. Another area widely valued by using the CVM approach is that of rural water supply (Whittington et al, 1990; Piper et al, 1997; North and Griffin, 1993).

The willingness to pay problem can be formulated as follows, assuming respondents want to minimise some level of expenditure,

$$\text{Min} \quad p \, \Delta x + q \, z \qquad (4\text{-}32)$$

Subject to some level of utility,

$$u^0 = u(\Delta x, z) \qquad (4\text{-}33)$$

where, p and q are prices given at a fixed level, Δx is the level of expenditure on the service or commodity such as water supply, z is a vector of private goods, and u^0 is the original level of utility. The optimisation problem yields an expenditure function in terms of prices, quantities and utility,

$$E = m(p, q, \Delta x, z, u^0) \qquad (4\text{-}34)$$

Which in term may be used to determine WTP,

$$WTP = m(p, q, \Delta x, z, u^0) - m(p, q, x^*, z, u^0) \qquad (4\text{-}35)$$

This in turn, may be used as the correct measure of welfare (Piper et al, 1997). The second approach to WTP is the indirect approach that uses various models such as hedonic property valuation, hedonic travel costs methods and varying parameter demand. The indirect methods are applied to data on the observed behaviour of water use including quantities of water used, time spent travelling to the point of collection and user perceptions of water quality, in order to determine the response of consumers to changes in the quantity and quality of the water service provided (Whittington, 1990).

The hedonic model is based on the notion that individuals or households choose a dwelling for rental or purchasing purposes based on the characteristics of the surrounding community, the dwelling itself, and the environment. Comparisons are then made between dwellings observed to have mostly identical characteristics but differ in one or two. The amount paid for the dwellings is then compared and the differences in value are assumed to indicate the amount that the consumer or purchaser is willing to pay for some characteristic evident in the one dwelling unit and not in the other. (North and Griffin, 1993), used hedonic property valuation to determine the value of water source and proximity to a number of rural households in the Phillipines.

The approach by North and Griffin (1993) was based on consumer theory and assumed that "all households were utility maximisers who divided their incomes between housing and non-housing goods".

> A housing unit can be modelled as a composite of several characteristics; for simplicity, limit them to two, proximity to the water source (h_1) and construction materials (h_2). These characteristics are purchased jointly, so the monthly expenditure on rent represents the total cost of the housing unit as a function of proximity to the water supply and materials... Under the usual assumptions of consumer theory, each housing characteristic can be valued in terms of the amount of other consumption that a household gives up to secure another unit of it, keeping in mind the complicated fact that each characteristic is bundled with others.
>
> (North and Griffin, 1993).

Based on these household trade-offs, the value of each dwelling and its related characteristics; bid-rent functions (similar to indifference curves) and hedonic price functions can be estimated. From the hedonic price function, marginal willingness to pay values can be determined by the derivative with respect to each characteristic, from which demand may be found.

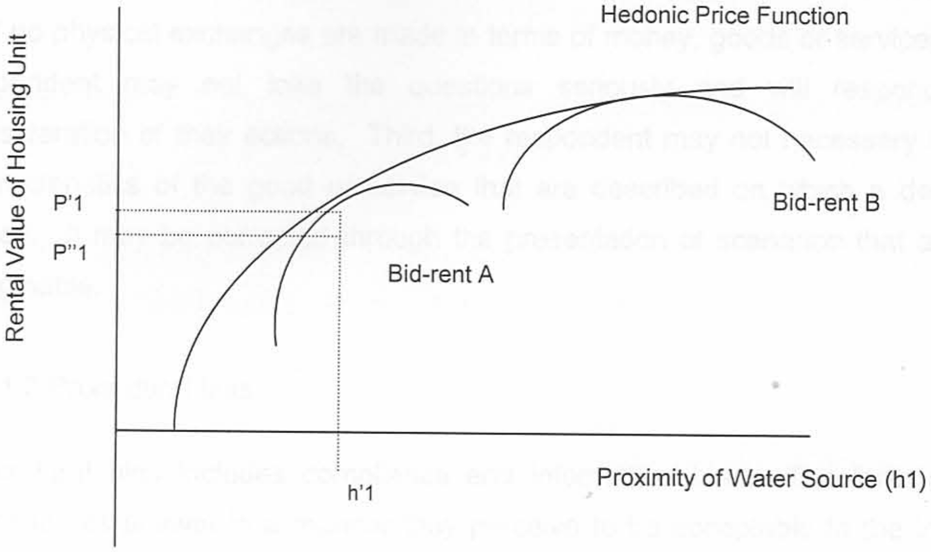

Figure 4-7: Example of a hedonic approach for one characteristic

Source: North and Griffin, 1993

The above figure, (figure 4-7), indicates that the amount that the household is willing to pay (p''1) for the level of the service (h'1) is overstated by the hedonic price function by (p'1). This in turn will overstate the marginal willingness to pay for the service.

4.6.1 Data biases in the willingness to pay approaches

Numerous biases have been identified in the literature, that influence the results obtained from WTP studies of water demand (North and Griffin, 1993; Piper et al, 1997; Rogerson, 1996; Whittington et al, 1990). They are the following:

4.6.1.1 Strategic bias

Strategic bias arises when respondents misrepresent their true positions by answering untruthfully in order to sway investment or policy decisions. Their WTP estimates may be either overstated or understated. This problem may be overcome through transparency of the interview process, where respondents are informed of the reasons for the questions and it is made clear that there are no costs associated with telling the truth and no gains from misrepresentation.

4.6.1.2 Hypothetical bias

Hypothetical bias may result for various reasons. First, the respondent may not understand the full implications of the decision under consideration as it only hypothetical and no physical exchanges are made in terms of money, goods or services. Second, the respondent may not take the questions seriously and will respond without due consideration of their actions. Third, the respondent may not necessary understand the characteristics of the good or service that are described on which a decision is to be based. It may be corrected through the presentation of scenarios that are familiar and imaginable.

4.6.1.3 Procedural bias

Procedural bias includes compliance and information bias. The former occurs when respondents answer in a manner they perceive to be acceptable to the interviewer, and may be corrected when respondents are aware that the costs associated with this type of response are greater than the costs associated with the truth. The latter, refers to the situation where the scenarios presented to the respondents do not accurately reflect reality and may be corrected through the presentation of accurate information.

4.6.1.4 Starting point bias

Starting point bias occurs where a certain price is randomly selected as the first bidding point in the process and respondents believe that this price or value is the one that they should select, and consequently do not give answers that would reflect their actions. Open-ended questions reduce the likelihood of this bias from occurring, as they do not offer an opening bid.

4.6.1.5 Vehicle bias

Vehicle bias occurs where respondents react to the method by which payment is made and not to the level of payment itself. Where this form of payment is familiar and represents a well-defined commodity, vehicle bias is unlikely to occur.

4.7 Summary

In the first part of this chapter, the role of the demand curve for water to better inform decision-makers about the impacts of pricing strategies and policies was discussed. In light of the National Water Act (s36, 1998), better-informed decision-making around pricing is imperative for the implementation of the act in its entirety. The literature indicates that research initiatives around the role of pricing and demand management for developing countries is limited in terms of quantitative measures.

The second part of this chapter, revised the approaches to demand schedule estimation and the studies carried out based on these approaches. From the literature review it became evident that most studies done to estimate water demand curves were based either on the pragmatic approach (Howe and Linaweaver, 1967; Dockel, 1973; Gibbs, 1978; Foster and Beattie, 1979; Howe, 1982; Billings and Agthe, 1980, and Hansen, 1996), or used the production function approach (Letey et al., 1985; Rao et al., 1988 and Juan et al., 1996). Those based on the pragmatic approach tended to estimate water demand for industry and domestic use, while those based on the production function approach tended to estimate water demand schedules for irrigation agriculture.

Most of the industry or domestic water demand studies set as their aim, the determination of price elasticities of demand, hence they continued from the demand schedule to determine the price elasticities of demand and marginal values for water. The irrigation agriculture studies, however, were based on spatially specific micro-economic data and focussed mainly on representing the relationship between price and demand. As a result, once the demand or marginal value schedules had been determined, the studies concluded without calculating the price elasticities of demand or the marginal values for water under irrigation agriculture.

Cost functions were rarely estimated and the studies reviewed here focussed specifically on water supply rather than demand. An example was the study carried out by Firestone (1982), which focussed on the marginal cost of water supply mains. This study was not based on duality theory and it did not attempt to determine price elasticities of demand or values for water supplied.

Non-economic approaches to estimating the demand for water are relatively young in South Africa. One study used contingent valuation to determine the price responsiveness of domestic water users to price adjustments in Gauteng and is discussed further in chapter 5.

Overall, many of these approaches to estimating water demand schedules are highly dependent on data availability, the spatial setting, the nature of the water sector and its demand management strategies. Many research gaps exist for either conducting primary research for water demand schedules particularly in developing countries or for applying and refining studies that have already been done to other regions.

Chapter five continues with the review of demand theory for water, focussing specifically on demand studies for urban household water use and the price elasticity of demand. An extensive literature review of household water studies is given. This is followed by the methodology selected for this study.

CHAPTER 5: A REVIEW OF STUDIES AND METHODOLOGIES TO ESTIMATE URBAN WATER DEMAND

5.1 Introduction

This chapter introduces the concept of price elasticity of demand for water and reviews a number of domestic water demand studies used to determine the price responsiveness of consumers. Interestingly, the majority of these studies refer to the 'price' of water underpinning, which a number of neoclassical assumptions are made. However, Gildenhuys (1997), states that some services are supplied by the government sector directly to the public sector by means of direct exchange, thereby foregoing the traditional transaction process directed by a price-quantity relationship. This implies that a relationship of "free contracting" exists, whereby the consumer (buyer) purchases a service "according to personal taste, need, preference and wealth", for which, correctly termed, "a user charge, consumer tariff or levy" is paid. Hence, the use of price in this and most of the reviewed studies refers not to a market price, determined under the premises of free trade but rather to the supply charges and tariffs imposed by a service provider, for these purposes, a water utility. Based on the interpretation of the outcomes of the studies reviewed, the methodology for this study is described, including the type of relevant variables and the form of the models to be used to estimate water demand in the case study area.

5.2 Price responsiveness of demand

Price elasticities of demand provide a measure of responsiveness in a standardised unit namely elasticity. The numerical values of elasticities can vary from zero (inelastic) to infinity (elastic). Price elasticities of demand are commonly represented by a negative sign, as demand curves slope downwards, changes in quantity associated with price tend to have the opposite sign to the change in price. However, elasticties can be reported without their respective signs in order to make the interpretation of the effects of price change on behaviour simpler. Without the sign, the interpreter can simply deduce that the larger the elasticity, the greater the responsiveness of quantity demanded to price. When the sign is retained, this interpretation will differ and the smaller the elasticity, the greater the responsiveness will be to changes in price. It is also important to understand that elasticties measure the changes in the quantity *demanded* by a consumer or household to the changes in price and not changes in the quantity of the good as a whole (Begg et al, 1991; Varian, 1996; selected articles on elasticity)

Defined as the ratio of the percentage change in quantity demanded to the percentage change in price, the price elasticity of demand provides an indication of the potential effectiveness of policy changes in price for particular commodities. Formulated in either of two ways:

$$\varepsilon_p = \frac{\Delta q / q}{\Delta p / p} = \frac{\% \Delta q}{\% \Delta p} \tag{5-1}$$

$$\varepsilon_p = \frac{p}{q} \times \frac{\Delta q}{\Delta p} \tag{5-2}$$

the value of ε (elasticity) changes along the slope of the demand curve and is usually negative in sign. Functional forms further impact on the nature of the elasticity; a linear demand curve reflects a different elasticity at each point while the cobb-douglas form has a constant elasticity. Elasticity proves to be a valuable measure in evaluating demand projection analysis for water-supply systems that aim to achieve at least some level of financial solvency. Both income and price elasticities may be derived.

Water utilities faced with rapidly growing water demands are looking to water demand management in order to address these pressures. One demand management strategy that is being widely investigated is that of pricing and the implied shifts in water rate structures, although these approaches are frequently implemented within the framework of education and conservation practices (Nieswiadomy, 1992). Due to the mounting emphasis on the role of pricing in water demand management a number of studies are focusing on measures of the responsiveness of demand to these pricing changes as a view to determine whether price could effectively curtail demand for water. The following literature reviews some of these studies and their elasticity results.

5.3 A review of water demand literature

This section reviews twenty water demand studies. These include studies based on cross-sectional data and those based on time-series data. Long-run and short-run elasticities are estimated, with most of the studies indicating that price elasticities for domestic water use become more elastic over time, as consumers have time to adjust their consumption patterns. Domestic demand, industrial demand, commercial demand and water for sprinkling or outdoor use are all reviewed. Income elasticities for many of the studies are also determined. The results and studies are summarised in (table 5-1) below.

Table 5-1: Research results for 20 studies on income and price elasticities for water demand

Study	Region	Year	Price Elasticities	Income Elasticities
Howe et al.	USA, 35 study areas – cross-sectional	1967	D[8]: –0.23 S[9]: -0.7 to – 0.16	D: 0.35 S: 0.4 to 1.5
Turnovsky	US,19 Massachusetts towns – cross-sectional data	1969	D: -0.3 I[10]: -0.5	-
Wong	Chicago: time series (1951-1961) Four community size groups: cross-sectional	1972	D: -0.02 to –0.28 D: -0.26 to –0.82	0.20 to 0.26 0.48 to 1.03
Young	Tucson, Arizona Time series	1973	D: -0.63 to –0.41	-
Dockel & Groenewald	Witwatersrand, RSA Cross-sectional data	1973	D: -0.63 to –0.84	-
Katzman	Penang Island – Malaysia Time series	1977	D: -0.1 to –0.2	0.24 to 0.30 0.32 to 0.39
Lynne et al	Miami, Florida Derived demand model	1978	C[11]: - 0.174	-
Gibbs, K.C.	USA – Miami, Florida	1978	AP[12]: - 0.62 MP[13]: - 0.51	-
Foster & Beattie	USA Generalised model	1979	D: -0.35 to –0.76	-
Billings & Agthe	Tuscon, Arizona	1980	LR: -0.27 to –0.49 Di: -0.12 to –0.14	-
Agthe & Billings	Tuscon, Arizona	1980	SR: -0.12 to –2.22 LR: -0.27 to –0.49 Di[14]: -0.12 to –0.15	-
Carver & Boland	Washington D.C metropolitan, Pooled time series and cross-sectional	1980	SR[15]: < [0.1] LR[16]: -0.2 to –0.7	-
Howe	Hopkins residential water use data	1982	D: -0.52 to –0.86	-
Hanke & De Mare	Malmo, Sweden, Pooled time series cross section	1982	D: -0.15	-
Chicoine & Ramamurthy	Illinois rural water districts, average price model	1986	MP: -0.61 2nd P variable: -1.02	-
Thomas & Syme	Perth, Australia, Contingent valuation	1988	D: -0.2	-
Hewitt & Hanemann	Texas, USA Household level panel data ('81 to '85)	1995	D: -0.57 to –0.63	0.15 to 0.16
Hansen	Copenhagen Pooled time-series data	1996	D: -0.003 to –0.1	CR[17]: -0.2
Nieswiadomy, M.L.	USA – Four regions	1992	AP: –0.22 to –0.6 MP:-0.11 to –0.17 PP[15]: -0.29 to –0.45	0.28-0.44
Veck & Bill	Thokoza, RSA Contingent Valuation Method	2000	D: -0.12 to –0.14 S: -0.19 to –0.47 Average: -0.14 to -0.18	-

Source: Own compilation

---

[8] D = Domestic use

[9] S = Sprinkling use

[10] I = Industrial demand for water

[10] C = Commercial demand for water

[12] AP = Average price model

[13] MP = Marginal price model

[13] Di = Difference elasticity

[14] PP = Perceived price model

[15] SR = Short run

[16] LR = Long run

[17] CR = Cross-price elasticity

5.3.1 Demand models using cross-sectional analysis

Gibbs, (1978), reviewed the use of certain price variables in residential water demand models, namely, marginal price and average price. Data was gathered from a large metropolitan area, Miami, Florida and used to form an empirical comparison of the two price formulations. Three hundred and fifty-five households were selected from which 1412 consumption and price observations were pooled. Seasonal residential water demand functions were estimated with the dependent variable in log form. Price and income elasticities were allowed to vary along the demand curve in response to the hypothesis that responses to price 'become more relevant as the price of water approaches a more significant portion of the consumers budget.' A marginal price demand equation was estimated. Further regression equations were also estimated to account for variables such as home value, the number of dishwashers and washing machines, number of bathrooms and residential acreage for income. The results based on the first two equations found that the responsiveness to price was overstated in the average price model, similarly the response to income changes was too. Furthermore, the average price equation was found to understate consumption response to the hot water heat variable and overstate the response on persons per household variable. Gibbs (1978) advised that the marginal price was the more appropriate price to use when defining price variables for estimating water demand models.

Similarly to Gibbs (1978), Nieswiadomy (1992), estimated urban residential water demand for four regions in the United States (the North Central, North East, South and West) based on a national cross sectional data set, by using two models one for average price and one for marginal price. This approach was expanded by including the price perception model by Shin [1985] that accounts for the fact that it is costly and difficult for consumers to determine the actual rate structure to which they are responding. The price perception model includes the perception price (P*) and not average or marginal price. P* is calculated as a function of marginal price and average price adjusted for some price perception parameter k. Such that,

$$P^* \quad = \quad MP\ (\ AP\ /\ MP\ )^{\ k}$$

Nieswiadomy (1992) also included dummy variables for the effects of conservation practices and public education on water demand, recognising the importance of these aspects of water demand management and not just the implications of pricing. The Shin (1985) based model is as follows:

$$
\begin{aligned}
\text{Ln } Q = \beta_0 &+ \beta_1 \ln \text{Income} + \beta_2 \ln \text{MarginP} + \beta_2 K \ln(\text{AP/MP}) + \\
&\beta_3 \ln \text{Rainavg} + \beta_4 \ln \text{Tempavg} + \beta_5 \ln \text{Persons} + \beta_6 \ln \text{Home 1939} + \\
&\beta_7 \ln \text{Ownoccupation} + \beta_8 \text{ Conservation} + \beta_9 \text{ Public awareness}
\end{aligned}
$$

The demand equations were estimated using a Box-Cox transformation indicating that a log-log model was an appropriate form to use. In order to test for heteroskedasticity as cross-sectional data was used, White's [1980] test was applied, indicating no heteroskedasticity. The overall results showed that variations in temperature below 18°c (65°F) had little or no impact on water demand. Analysis of the parameter k indicated that consumers reacted to average prices, however Nieswiadomy and Molina [1991] found that consumers reacted to marginal prices in increasing block structures and to average prices in decreasing block rate structures.

Howe and Linaweaver (1967), estimated the impact of price on residential water demand and its relation to system design and price structures by using cross-sectional data for the United States. The data set was further disaggregated, separating domestic and sprinkling uses, maximum day and peak hour demands, utility revenue and price structures, and economic and climatic characteristics. Thirty-nine study areas were selected and categorised into five areas by climatic conditions. Two functional forms of the water demand equations were estimated based on the premise that theory failed to specify a unique functional form for the purpose of the study. Both linear and cobb-douglas (multiplicative) functions were fitted. The price variable was one of marginal price calculated as the sum of the water price and water-based sewerage charges at the households actual position in the water rate structure, (Howe, 1982). The problem of a spurious demand curve was addressed and it was found that the demand curve for this study was not spurious. The results indicated that separate domestic demand equations should be used for metered and flat-rate areas. Population density appeared to be the only variable significantly affecting demand in the flat-rate and septic tank areas. Billing frequencies and the regional price index did not appear to significantly influence demand or price elasticities. The study was limited in its ability to provide information on the relative frequency or duration of 'extreme demands'. Further information on the cost structures of utilities was recommended before conclusions on optimum price structures are drawn. Information on the factors affecting these costs was limited. Further research (theoretically and empirically) on marginal cost impacts where excess capacity exists, and differences between the nature of short-run and long-run variable costs was recommended.

Turnovsky (1969), estimated demand functions for water where supplies were known to be stochastic. Separate functions were estimated for household and industrial demand. Cross-sectional data was used for 1962 and 1967 from nineteen Massachusetts towns in order to determine whether the response by consumers changed due to the drought that occurred during the intervening years. Ordinary least squares regression was used to estimate the equations. The variables included were supply variance in gal/day squared, included based on the nature of consumer theory where commodities are uncertain in supply, (Turnovsky 1968 and 1969); average price of water (metered revenue / metered gallons used); index of per capita housing space (average number of rooms per dwelling / median number of occupants per dwelling); percentage of population under 18; index of per capita industrial production; regressed against planned per capita consumption in gal/day.

$$\text{Domestic demand, } x_i = \alpha_0 + \alpha_1\sigma_1^2 + \alpha_2 p_i + \alpha_3 h_i + \alpha_4 P_i$$

$$\text{Industrial demand, } x_i = \beta_0 + \beta_1\sigma_1^2 + \beta_2 p_i + \beta_3 Ip_i$$

The models were based on the premise that households tended to use water according to their needs, these needs being derived demands determined by the number of water using appliances within a dwelling unit. Therefore, it was assumed that water use would be a function more closely related to measures of real estate than income flow. The results indicated that price, uncertainty measured by supply variance and dwelling space were significant variables for household demand, whereas dwelling space proved to be insignificant for industrial demand. Furthermore firms appeared to be more responsive to price changes and uncertainty than households as they tended to be more highly influenced by economic factors than households. The price elasticities for the variables were estimated at the mean values of the variables. This study indicated that substantial price and variance changes are required to bring about definite changes in consumption. Government rationing was proposed as a means to reduce domestic water use.

5.3.2 Demand models using time-series analysis

Referred to in a number of studies on demand elasticities, Wong (1972), aimed to solve the question of how price, income and average summer temperature affect water demand. Fifty-nine suburbs in the Chicago area were selected for the study. Two approaches were adopted, the first was a time series analysis of the area over the period 1951 to 1961, the second was a cross-sectional analysis of the 103 municipal supply systems stratified into groups by size: 25,000-over; 10,000-24,999; 5,000-9,999 and 4,999-less. For the time-series analysis, prices and income were deflated to 1961 constant dollars. For the cross-sectional analysis the temperature variable was omitted as it was found to be relatively uniform across the study region, thereby insignificantly influencing per capita water demand. Both temporal and spatial impacts on water consumption were investigated. Ordinary least squares multiple regression analysis was used to model average per capita water demand as a function of price per unit, average household income and average summer temperature. Substitutability between surface and ground water was considered zero and cross-effects were omitted. However, the 103 supply systems tended to be more dependent on ground water than surface water enabling a comparative analysis to be done between the two sources. A logarithmic model was used. The differences in elasticities indicated that for Chicago itself the responsiveness was small (inelastic) mainly due to the extremely low water rate, this rate however was higher for the outer lying suburbs as a result of higher distribution costs and greater distances from the supply source. The time series analysis appeared to suppress the magnitude of the income elasticity. The results further indicated that groundwater tended to be more price elastic than surface water sources and no distinction was made between short and long-run price elasticities as this study focussed more on the spatial effects of price and demand.

In response to the study done by Wong (1972); Young (1973), recognised the dirth of empirical work done using time series data. As a result, he studied the effects of population, price and income on the demand for municipal water supplies in Tucson, Arizona for the period 1946 to 1971, using time series analysis. Marginal value changes in water deliveries were not used due to a lack of sufficient data and average charge per 1000 gallons was used as the measure of price. This charge was then deflated using the consumer price index for 1968. Active service was used as a measure of population and a proxy for per capita income was 'defined in terms of retails sales per capita per unit time. Rainfall, temperature and evaporation measures were obtained from the local weather bureau. Ordinary least squares was used to estimate the model and the temperature, evaporation and income variables were omitted due to insignificant statistical results and hypothesis inconsistency. As a result, only average charge and rainfall, were included as explanatory variables. As seen in the study by Wong [1972] no distinction was made between short and long-run price elasticities.

Moving from the United States, Katzman (1977), estimated the income and price elasticities of demand for domestic water for Penang Island, Malaysia. Cross-sectional data from 1400 households was used to derive elasticities for low income (per capita income less than US$300) and higher income families. Time series data of a sub-sample of mixed income individuals was also used to estimate short-run price elasticities. Average water consumption was transcribed from the meter books and the households were divided into four categories: very poor (<US$600); poor (US$600 – 2000); middle (US$2000-3200) and rich (US$3200<). Average monthly consumption was regressed against income dummies; number of persons per household, disaggregated by age; urban versus rural residence; and ethnicity to account for cultural practices (these differences were however reduced to those of family size, income and location and were ignored). The income groups, the very poor and poor showed a marginal effect on water consumption due to income, this was not the case for higher income groups. Family size proved to be a major indicator for higher water consumption demands. Income elasticities of demand were estimated for the rural and urban income groups by dividing the percentage increase in consumption by the percentage increase in income. An increase in the water rate was evidenced during the period and was accounted for by grouping the urban and rural areas by neighbourhood and rate class. Due to the use of time series data, it was assumed that the effects of changes in technology and cultural practices were not accounted for, making the estimates short-run estimates. Another interesting feature of this study was that it used a different method to estimate price and income elasticities to those used previously. An 'economic demand projection model' was also derived based on growth in demand and not per capita consumption coefficients. It was found that demand projections incorporating elasticities tended to be more sensitive to policy changes than the traditional approaches.

Foster and Beattie (1979), presented a generalised Fourt[18]-type model allowing for the categorical effects due to regional and size-of-city differences on urban residential water demand for the United States of America. The model was based upon the neo-classical theory of consumer demand. The advantage of the model was that it allowed cities that were not atypical from those used in the model to use the parameter estimates in determining the effects of various policies, when demand was 'invariant' to city size. The model was applied to various functional forms with price in the exponential and all other explanatory variables in the power form. Dummy variables were then added in three steps: first for the constant factor; second for the constant factor and the price coefficient; and third for the former two and the income coefficients. Ordinary least squares was used to estimate the regression coefficients for 218 cities. The signs for the various coefficients were: negative for price; positive for income and number of residents; and negative for

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[18] See Fourt, 1958.

rainfall. This study was able to account for changes in constant factor and price coefficients across regions by including the dummy variables for region.

5.3.3 Demand models redefined accounting for price structure variations

In order to explain the nature of advances in economic consumer behaviour theory with regard to price structures (increasing or decreasing block rates), Billings and Agthe (1980), used a model based on two price-related variables (marginal price and a difference variable) and an income variable to estimate the demand for water under block rate pricing or where service charges appeared in the rate schedule. Data for Tucson, Arizona, for the period 1974 to 1977 was used. The implicit signs expected for the difference coefficient of income was positive (water is a normal good) and for the price difference variable and marginal price variable, negative. However, where there were no block-rates the difference variable was expected to have a value of zero. Due to large inflationary changes during the study period both real values and nominal values of the variables were used, real values were adjusted by the consumer price index. Three functional forms were estimated namely, a linear model, a multiplicative model and a log transformation model from which direct elasticities were estimated. The results indicated that the estimations were free from serial correlation and that the estimates for price elasticities were stronger than previously found when only one price variable was included in the model.

In response to the limitations of former studies that aimed to analyse water demand using static models, Agthe and Billings (1980), recognised that current water use was strongly influenced by historical water use patterns. They used a dynamic model to estimate water demand and accounted for this relationship. Monthly residential demand for water in Tucson, Arizona, was estimated for the 1974 to 1977. The static, Fisher-Kaysen, Koyck, Bergstrom flow adjustment and stock adjustment econometric models were tested and the price elasticity of demand was estimated. Both marginal price and a second price related variable (*difference*) were used to account for block rates and fixed charges in the rate schedules (Taylor, 1975; Nordin, 1976; and Billings and Agthe, 1980). The Fisher-Kaysen model produced poor statistical results and was omitted, the linear flow adjustment model overestimated the short-run marginal price elasticity of demand for water, while the stock and logarithmic flow adjustment models indicated insignificant t values on some important variables. The linear and log versions of the Static and Koyck models however, showed strong statistical results for long-run price elasticities of water demand Furthermore the equal-in-magnitude-opposite-in-sign (EMOS) hypothesis referring to the income and *difference* coefficients was found to be untrue for magnitude but true for sign. Further research using different data sets and time-periods was proposed to resolve the inconsistencies indicated.

Using pooled time series and cross-sectional data, Carver and Boland (1980), estimated the short and long-run effects of price on municipal water use, thereby distinguishing between short and long-run responses. Pooled time series and cross-sectional data for the Washington D. C. metropolitan area were fitted to a flow adjustment model of the Nerlove (1958) type. Furthermore, a distinction was made between seasonal and non-seasonal water use, using dummy variables. The results showed that response changes to price for aggregate annual water use in the short-run were small falling below the absolute value of 0.1, while long-run responses tended to fall into the range of –0.2 to –0.7 (similar to the ranges found in other studies). Seasonal price elasticities, however, appeared to be much smaller than those previously estimated.

Using advances in consumer theory, Howe (1982) derived more appropriate household water demand functions that accounted for the effects of rate structures. Marginal price elasticities were re-estimated from the John Hopkins Residential Water Use Project data of 1963-1965 for the USA. The study stated that marginal price alone did not adequately reflect the effect on the consumer of various rate structures. Recognition of the inclusion of the 'difference variable' in demand functions as a superior approach to that of using average or marginal price was made. The value of D was also expected to be positive for decreasing block rate structures and positive for increasing block rate structures (Billings and Agathe, 1980). The revised models included the 'D' variable and changed the household demand variable to total household demand and not in-house and sprinkling use (this division was regarded as inappropriate due to the observation that household positioning on the rate schedule depended on total demand per billing period).

In response to the developments in consumer theory Schefter and David (1985), estimated residential water demand under multi-part tariffs using aggregate data. Their results indicated that mean marginal price and mean difference are the appropriate measures to use when working with aggregate data. It was proposed that more information on residential water demand be required in order to do estimations under multi-part tariffs. Further research on the form of water distribution across households and its variation as a function of rate structure was proposed.

In light of the continuing debate surrounding the use of marginal cost pricing and some difference variable (Nordin, 1976) versus the use of average cost pricing (Foster and Beattie, 1981), Opaluch (1982) proposed an hypothesis concerning the measure of price to which consumers responded. The results indicated that a proper model of consumer behaviour is a case specific empirical question.

Following the procedures outlined by Opaluch (1982), Chicoine and Ramamurthy (1986), used household level data from a sample of Illinois rural water district customers to test which price consumers responded too when potable water was sold under declining block-rate structures. The model employed was based on the utility maximising framework used by Opaluch (1982), an average price model with the price measure decomposed into a marginal price and a difference variable, applied to time-series and cross-sectional data. The results indicated that neither the marginal price nor the average price models were appropriate models of consumer behaviour as they inadequately explained consumer demand for rural domestic water. However, the decomposed measure of average price model proved to be the correct form for the Illinois rural water districts. Further research efforts on the versatility of this more general model along with the simultaneity issue (responsiveness to two pricing structures) were proposed.

5.3.4 Demand models using discrete and continuous choice specifications

Another specification of the demand model under block rate pricing was presented by Hewitt and Hanemann (1995), using a discrete and continuous choice model (D/C) approach to residential water demand. Based on the same data set used in the Nieswiadomy and Molina (1989) study of household level panel data for summer months from 1981 to 1985. Four estimations were run. The first three were regression estimations of the types: logarithmic form of the ordinary least squares (OLS); instrumental variables (IV); two-stage least squares (2SLS); and the fourth was the D/C choice model. The D/C model allowed the error term to be separated into a heterogeneous preferences error and a perception error. The former pertained to the econometrician and the latter pertained to the consuming household subsequent to decision-making. Therefore the demand for household water was estimated as a function of the price of water (p); household income and *difference* (y + d); sociodemographic variables (Z) and error terms (ε, η); where (δ, α, μ) were the unknown parameters of the utility function. The D/C model was based upon marginal prices and implied that households were aware of the price schedules they faced, making the debate over the use of average or marginal price irrelevant. The model was however, more costly than traditional models to run, in light of its strict specification assumptions.

5.3.5 Derived demand from a household production function

Unlike the previous studies on residential water demand, Hansen (1996) derived a demand function from a model of household production of final consumption goods including water, energy and other aggregate inputs. The estimation was run on pooled time-series data for the Copenhagen metropolitan area. Two production functions, one based on aggregate water dependent final consumption and the other on water independent final consumption were described. Through cost minimisation, a water demand function was derived from which marginal final good production costs were found. Differentiation of this function then yielded the components of price, income and weather effects that were estimated using four functional forms of the standard water model. They were the standard linear and log-linear, and the linear and log-linear sprinkler models (accounting for sprinkling water demand). Ordinary least squares estimations were run and the results indicated that residential water demand was generally income and water price inelastic and that meteorological variables also significantly influenced water demand.

The above-mentioned studies indicate that price elasticities for residential water demand vary considerably. Espey, Espey and Shaw (1997), used a meta-analysis to determine which factors systematically affected price elasticity estimates for residential water demand. The meta-analysis used empirical estimates from previous studies (price elasticities) and attempted to explain their variation by using 'inter-study differences as explanatory variables' such as: functional form, cross-sectional versus time-series data, price specification, rate structure, location and season. Twenty-four articles on price elasticity estimations for the United States were reviewed, yielding 124 estimates of price elasticities and 27 explanatory variables excluding the constant term. The results indicated that the evapotranspiration rate, rainfall, pricing structure and season had the most influential effects on the demand for residential water. Significant differences were also noted between short-run and long-run price responsiveness and between residential and commercial demand. Population density, household size and temperature did not however appear to significantly affect the price elasticities of water demand for the USA studies. It was noted that policy-makers would be advised to consider these aspects when selecting a particular study and its corresponding elasticity for decision-making.

5.3.6 Pricing policies and their impacts on elasticity results

In conjunction with consideration of the impacts of explanatory variables on the elasticity results yielded in many of the above-mentioned studies, the underlying pricing policies that direct the water management strategies in the respective countries and regions also need to be accounted for and assessed as they have direct implications for the specifications of the price variables in each study. The following table, table 5-2, outlines a number of related studies, their pricing policies and the resulting price elasticities of demand. Another aspect of interest is the wealth of respondents in relation to their responsiveness to price changes but due to information shortcomings, a review on wealth was not carried forward here.

The majority of studies fell into the three typically observed pricing structure categories, flat-rates, fixed rates and decreasing or increasing block rate pricing. Flat rates and fixed rates structures can be dealt with relatively simply in the modelling and one generally expects that consumers have a good understanding of the implications of water use for their bills at the end of each month, where metering takes place. Block rate pricing structures on the other hand are more complex to deal with in the modelling of water demand and consumers are often unaware of the impacts of these pricing structures on their final water bills, making them less responsive in the short-run to the price changes from one block to the next. These types of pricing structures also have the curious effect of leading to a positively signed price elasticity of demand when consumers a re faced with increasing block rate tariffs. This is simply explained by the increase in demand for water being met by an increase in the price of water as the consumer moves into the next pricing block. This effect is discussed in detail in chapter 7 with specific application to the Tshwane study. Interestingly, the price elasticity of demand results from the studies reviewed below seem to vary insignificantly with the different pricing policies and this may be due to the observation that on average they tend to face similar pricing structures.

Table 5-2: Pricing policies for different price elasticity of demand studies

Study	Region	Year	Pricing policies	Price Elasticities
Gibbs, K.C.	USA – Miami, Florida	1978	Mixed combinations of flat-rates for the first block of water consumed, fixed rates, and decreasing block rates	AP: - 0.62 MP: - 0.51
Nieswiadomy, M.L.	USA – Four regions	1992	Block price structures	AP: –0.22 to –0.6 MP:-0.11 to –0.17 PP: -0.29 to –0.45
Howe et al.	USA, 35 study areas – cross-sectional	1967	Metered and flat-rate based pricing	D: –0.23 S: -0.7 to – 0.16
Turnovsky	US,19 Massachusetts towns – cross-sectional data.	1969	Multiple rate structures	D: -0.3 I: -0.5

Table 5-2: Pricing policies for different price elasticity of demand studies continued

Study	Region	Year	Pricing policies	Price Elasticities
Wong	Chicago: time series (1951-1961) Four community size groups: cross-sectional	1972	Differential pricing structures and higher distributional costs with distance from source	D: -0.02 to –0.28 D: -0.26 to –0.82
Young	Tucson, Arizona Time series	1973	A basic delivery fee for a specified level of water delivery, successive increments priced at decreasing unit cost	D: -0.63 to –0.41
Katzman	Penang Island – Malaysia Time series	1977	-	D: -0.1 to –0.2
Lynne et al	Miami, Florida Derived demand model	1978	-	C: - 0.174
Foster & Beattie	USA Generalised model	1979	-	D: -0.35 to –0.76
Billings & Agthe	Tuscon, Arizona	1980	Fixed charges and block rates	LR: -0.27 to –0.49 Di: -0.12 to –0.14
Agthe & Billings	Tuscon, Arizona	1980	Fixed charges and block rates	SR: -0.12 to –2.22 LR: -0.27 to –0.49 Di: -0.12 to –0.15
Carver & Boland	Washington D.C metropolitan, Pooled time series and cross-sectional	1980	-	SR: < [0.1] LR: -0.2 to –0.7
Howe	Hopkins residential water use data	1982	-	D: -0.52 to –0.86
Hanke & De Mare	Malmo, Sweden, Pooled time series cross section	1982	Metered pricing	D: -0.15
Opaluch	USA, Utility maximising framework	1982	Block pricing structure	-
Schefter & David	Wisconsin, USA	1985	Multi-part tariffs	-
Hewitt & Hanemann	Texas, USA Household level panel data ('81 to '85)	1995	Block rate pricing	D: -0.57 to –0.63
Hansen	Copenhagen Pooled time-series data	1996	Simple one or two part tariffs with marginal costs for households independent of volume consumed	D: -0.003 to –0.1
Chicoine & Ramamurthy	Illinois rural water districts, average price model	1986	Declining block rate structure	MP: -0.61 2^{nd} P variable: -1.02
Thomas & Syme	Perth, Australia Contingent valuation	1988	Privately extracted groundwater and public mains supply on a two-part block tariff system	D: -0.2
Dockel & Groenewald	Witwatersrand, RSA Cross-sectional data, macro-econometric model	1973	Flat rate and increasing block rate pricing	D: -0.63 to –0.84
Espey et al.	Multiple study results across regions, a meta-analysis	1997	Multiple rate structures	-
Veck & Bill	Thokoza, RSA Contingent Valuation, Econometric approach	2000	Based on CVM approach and the related tariffs for levels of service as stated in the study, and increasing block rates	D: -0.12 to –0.14 S: -0.19 to –0.47 Average: -0.14 to -0.18

Source: Own compilation

5.4 Outcomes of the domestic water demand studies

From the above reviews, it is evident that several different models have been used in the literature. Not only do these models differ significantly, but their independent variables also vary extensively. One such variable that is frequently reviewed is the choice of a price variable. Some use marginal price as the price variable, others use average price as the price variable, some use Shin's [1985] price perception model and still others account for the effects of fixed fees and inframarginal prices by using the 'difference variable' or rate structure premium. Endogeneity of the price variables is thoroughly covered in most of the literature and tests such as the Hauseman (1978) chi-square test were used to ensure econometric viability.

Income and substitution effects are discussed. However, the income effect of price changes for water resources is considered minimal and therefore relatively insignificant. Water is also characterised as a good with limited substitutes and the substitution effect in most studies is ignored, except for (Hansen, 1996) who included energy as an independent variable in the water demand model, deriving a cross-price elasticity of –0.2. Another aspect that clearly influences estimation results is the time frame of adjustment. Changes in quantity demanded are expected to be greater the longer the period of adjustment. Evidently, consumer behaviour indicates that users tend to over-adjust to price changes in the short-term and then revert to long-run equilibrium positions, resulting in short-run price elasticities being larger than long-run price elasticities. (Keller, 1975; Carver, 1980) found that water does not have a permanent elasticity of demand, but a temporary effect on limiting demand. Water use is observed to return to the rate of usage seen prior to price increases, in only short time frames. The reason for this behaviour is assumed to be due to lags in users' responses to price adjustments, in conjunction with their inability to differentiate between nominal and real prices.

The price variable is not the only independent variable that influences the demand estimations. Many other variables are identified as having significant effects on demand. Where a period of inflation coincides with water price changes, a frame of mind may be cultivated where consumers become less concerned with water costs and their implications for demand, (Young, 1973). Rising incomes also ensure that water costs form a smaller portion of total household expenditures, resulting in water consumption becoming less responsive to price, (Young, 1973). User profiles defined by multiple-family dwellings and swimming pools tend to be characterised by an increasing proportion of total water consumption. Furthermore, households that are fitted with larger numbers of water using durable's such: as washing machines, dishwashers, bathtubs and showers tend to be larger consumers of water than those with fewer water using appliances. Price increases do not appear to impact on water demand for these goods. They do however play a more significant role in adjusting user habits such as: showering times, lawn watering and car washing.

The majority of studies discussed above tend to be limited by static estimations and do not account for the simple observation that consumers' decisions depend to some extent on the price of a good in the previous year. It may therefore be wise to include price lags in the demand models, moving from static estimations to dynamic estimations as reported in (Agthe and Billings, 1980). The debate on functional form has been limited to regression methods of estimation, some however have included instrumental variables and two stage-least squares, (Hewitt and Haneman, 1995). Model specifications and estimation techniques were initially based on demand equations using either an average price or marginal price variable (Howe and Linaweaver, 1967). Taylor (1975) and Nordin (1976), recognised the discrepancy in decision-making by the consumer between the actual price paid and the expected price to be paid. To counteract this, a difference variable (discussed earlier) was introduced to the model. Similarly, Shin (1985) and Nieswiadomy (1992) introduced a perceived price specification. A more general model was then estimated that accounted for both marginal price and average price (Opaluch, 1982; Chicoine and Ramamurthy, 1986). These models are however all limited by their inability to model the choice of block in which to locate consumption (Hewitt and Hanemann, 1995). Model specifications also have significant effects on the estimates of elasticities, indicated by (Howe, 1982).

The choice of explanatory variables and functional forms further determine the nature of the elasticities. Wong (1972) and Gottlieb (1963) used power forms for their models, thereby obtaining constant elasticities throughout the ranges of their variables. The shortcoming of this approach lies in its implicit rejection of the possibility that water may become "satiated" in various uses. This limitation may be overcome by including price in the exponential form of a model, allowing the elasticities to "vary directly with price". This approach also allows for a quantity intercept to be obtained when price is zero (satiated), (Foster and Beattie, 1979). Where the independent variables maintain stable differentials across their units, then the price elasticity estimates will be more likely to represent the long-run. Furthermore, Higher elasticities are expected for outdoor water demands than for indoor water demands, (Howe and Linaweaver, 1967).

Data selection further complicates the derivation process. Both time-series data and cross-sectional data have their limitations. These data sets may produce further varied results depending on whether they are aggregated or disaggregated. The majority of the studies reviewed here are based on cross-sectional data as it appears to be more comprehensive and easily obtained in many areas. Time series data does have the advantage of enabling one to distinguish between the short-run and the long-run.

Econometric studies of water demand may also be based on primary or secondary data, (Carer, 1980).

Evidently, a wide range of studies has estimated the demand functions for numerous countries within the developed and developing world (Howe and Linaweaver, 1967; Dockel, 1973; Gibbs, 1978; Foster and Beattie, 1979; Howe, 1982; Billings and Agthe, 1980; Hansen, 1996). There are however very few studies on demand estimation and elasticity derivation done for developing countries. In South Africa only one study using empirical analysis for domestic water demand has been completed for the former Witwatersrand region (Dockel, 1973), the Water Research Commission has also completed a study based on the pragmatic approach for household water demand in two areas, namely Alberton and Thokoza. This study uses contingent valuation to determine the price elasticities of demand for water, an econometric approach was also taken but the results did not prove to be statistically significant (Veck and Bill, 2000).

In light of the above discrepancies and various determinants of demand, policy makers are advised to act with caution when selecting a price elasticity of demand for decision-making purposes.

The objective of most empirical studies on water demand management is to determine the "price elasticity of the demand for water rather than other welfare measures" (Hewitt and Hanemann, 1995). Similarly, evidenced by the existing literature, research efforts on the implications of demand management through pricing mechanisms in South Africa is sorely needed. The objective of this research effort will be to estimate the demand function for water in the Tshwane Metropolitan area of South Africa, using cross-sectional and time-series data from which price elasticities of demand will be estimated.

5.5 Econometric specification of demand for water in Tshwane

Supply-side estimation would depend on the use of the theory of profit maximisation or cost minimisation from which input demand and output supply functions could be derived. This would require data to be collected on budgets and total expenditure for water, as well as data on the costs associated with water supply such as, administrative costs, capital costs, transfer costs and subsidy costs. This kind of data was not however available at such a disaggregated level and so the theoretical approach based on supply was not followed for this study.

The theoretical approach based on consumer theory assumes that all consumers are utility maximisers from which Marshallian demand functions can be estimated. This approach is reliant on household level data. Demand systems may also be estimated using the AIDS or LES approaches but these require the specific disaggregation of data outlining household budgets, shares spent on food, electricity, water, and other goods on a monthly basis. This approach would require the compilation and distribution of household specific questionnaires such an approach was not taken for this study.

Due to the availability of secondary data on the prices and quantities of water demanded by consumers, including the number of consumers, regional income, and various weather variables, it was decided that the pragmatic approach should be used to estimate Marshallian demand functions for water disaggregated by area within the municipality. A systems approach was then applied for the whole of the Pretoria Municipality area and an aggregate demand function was obtained. Ordinary least squares was used to run the estimations, while various functional forms were changed to assist with the estimation of elasticities. From the estimated demand curves, price elasticities of demand were derived and analysed. The respective data, equations and elasticity results are shown in the next chapter, chapter six.

5.5.1 Choice of functional form

The linear, logarithmic and translog functional forms were applied to the demand models. The statistical results from each varied only slightly. In light of the hypotheses and the need to determine price elasticities of demand, the logarithmic functional form was adopted. This allowed for the direct observation of elasticities and their respective levels of statistical significance.

5.5.2 Data collection and model development

5.5.2.1Hypothesised relevant variables

Many variables have been identified throughout the literature on domestic water demand. These include price variables ranging from average price to marginal price, specifically formulated prices and aggregated prices; weather variables such as precipitation and temperature with the usual focus falling on maximums; seasonal variables such as wet and dry seasons or summer, autumn, winter and spring, these variables are often included as dummy variables within the models. Other variables included become dependent on the nature of the study such as: population estimates, household demographic charatersics, household infrastructural characteristics, type of water supply, nature of demand, time of day, and household income.

The variables selected for this study included monthly data on precipitation, maximum temperature, average price and marginal price, seasonal variables and the quantity of water consumed. Annual data that was adjusted to monthly data was also collected for the number of users, household income, and population.

5.5.2.2 Selection of variables for the empirical analysis

The data set used for this study was obtained from the Tshwane Municipality for 1995 to 2000. It contains information on aggregate monthly household expenditure on water for different regions within the municipality. Expenditure in South African rands and quantities consumed in kilolitres were obtained directly, from which average prices were derived. The marginal prices were determined as the difference between average prices for different consumption classes, ranging from 0 to 0.2kl; 0.2 to 0.7kl; 0.7 to 1.0kl; and more than 1,0kl's of the daily water consumption. The number of users in each category was also included.

The monthly weather data on temperatures and rainfall was obtained from the South African weather bureau for the five years of the study period. It was then grouped according to the countries rainfall and temperature patterns into four seasons, summer, autumn, winter and spring. These variables were included in the model as seasonal dummies.

Data on income disaggregated by the respective municipal regions was limited and it was finally decided to use population and household income data for Mamelodi and Attridgeville from the DBSA. This data was for the year 1995 and was adjusted using an inflation index to obtain data for the five-year period. A shortcoming of this approach is that the data is highly normalised and does not account for subtle adjustments in income over the period. Income for the whole of the Tshwane municipality was obtained from the SSA 1996 Census and was adjusted using the inflation index to obtain a five-year data set.

The different user categories for the Tshwane municipality are described in (table 5-3). The reason for the distinction between Mamelodi, Attridgeville and the rest of Tshwane was to enable some level of the effect of income on demand to be captured.

Table 5-3: User scales for Tshwane

User category	Description
Scale A	Agricultural Small-holdings
Scale B	Residential housing
Scale C	Duplexes / Simplexes
Scale D	Domestic businesses
Scale E	Old age homes
Scale F	Large industrial user
Scale G	Attridgeville
Scale H	Mamelodi

These user scales are further disaggregated into user classes, based on the amount of water extracted over the stipulated daily allowances. These classes are shown in (table 5-4). Due to the nature of the data, classes 1a and 1b were excluded from the study as was class 4. The difference between prices from class 1 to class 2 and from class 2 to class 3 was used to determine marginal prices for water use, hence the inclusion of variables marginal price 1 (P_{mp1}) and marginal price 2 (P_{mp2}) in the models. For the purposes of clarity, demand schedules were also derived for each user class, individually and aggregated, these are reported as Scale A/ B/ C/ D/ E/ F/ G/ H, level low/ medium/ high/ total.

Table 5-4: User classes for Tshwane

Description by Tshwane	Class for this study	Level of use
Less than 0,2 kl of the daily consumption	1	Low
Between 0,2 and 0,7 kl of the daily allowance	2	Medium
Between 0,7 and 1,0 kl of the daily allowance	3	High
More than 0,1 kl of the daily allowance	4	-
Up to 30% of total daily allowance	1a	-
More than 30% of total daily allowance	2a	-

Assuming water consumers derive utility from consuming characteristics of a composite commodity, the vector of rainfall characteristics, vector of temperature characteristics, vector of price characteristics, vector of user characteristics and the vectors of seasonal characteristics are included in the specified demand model. The set of dependent and independent variables included in the demand models are given in (table 5-5).

Table 5-5: Base model variables

Variable name	Description	Unit of measurement	Expected sign
Dependent variables			
Q_w	Quantity of water demanded	Kilolitres	+
Independent variables			
P_{ap}	Average price of water	Rand / unit	(+) - **
P_{mp}	Marginal price of water	Rand / unit	-
$P_{ap(-6)}$	Average price lagged by the number of months in parenthesis	Rand / unit	-
$P_{mp(-6)}$	Marginal price lagged by the number of months in parenthesis	Rand / unit	-
Rain	Rainfall	Millimetres per month	-
Maxtemp	Maximum temperature	Degrees celcius per month	+
Users	No of users	Aggregated unit	+
Pop	Population	Aggregated unit	+
HHI	Household income	Rands	+
D1	Dummy for summer		+/-
D2	Dummy for autumn		+/-
D3	Dummy for spring		+/-
C	Constant (often takes on the dummy value for winter)		+/-

**The expected sign for the average price is negative, although when a consumer faces block rate pricing structures the sign is often positive. Current literature is investigating ways in which to deal with these complexities.

5.5.2.3 Transformation of variables

When estimating the log form of the water demand model the independent variables are expressed in their natural logarithmic forms. When some of the observations report zero or negative units problems arise in obtaining an output. In order to address this shortcoming, the respective units were scaled by a constant (either one or ten) making all independent observations larger than zero. By doing this, the sample size of sixty observations was maintained.

The rainfall variable was lagged by one month for all the models as this adjustment allowed for the Tshwane billing data to correspond directly with the rainfall data, so that results represented the consumer response for the same period.

The price variables were lagged for a period of between three and thirty months depending on the statistical significance or the results, allowing for comparison between short-run and long-run responses to price changes.

5.6.3 Specification of the empirical model

Equation 5-3, shows the specification of the empirical normalised demand function. The derived price elasticity of demand and income elasticity are the coefficients of the respective variables in the model.

Equation 5-3:

$$
\begin{aligned}
LnQ_{water} = {} & \beta_o + \beta_1 \ln average\ price + \beta_2 \ln marginal\ price + \beta_3 \ln average\ price\ (lagged) + \\
& \beta_4 \ln marginal\ price\ (lagged) + \beta_5 \ln average\ rainfall + \beta_6 \ln maximum\ temperature + \\
& \beta_7 \ln household\ income + \beta_8 \ln population + \beta_9\ dummy1 + \beta_{10}\ dummy2 + \\
& \beta_{11}\ dummy3 + \beta_{12} \ln no\ of\ users
\end{aligned}
$$

Different combinations of the independent variables were estimated for each user category at different scales using OLS, until a best fit was obtained.

Chapter five set out to identify the appropriate methodology for building demand functions for residential water users. After an extensive literature review process the pragmatic approach was selected and the relevant hypothesised variables were identified. The latter half of the chapter introduced the expected economic results behind the estimations, and the single equation specifications and results are reported in the next chapter.

CHAPTER 6: RESULTS OF DEMAND ESTIMATIONS

6.1 Overview of the chapter

Different combinations of the stipulated demand function were estimated using three different functional forms mentioned in chapter five. The logarithmic functional forms were accepted as the most useful for the purposes of this study, especially as the statistical results differed insignificantly from those of the linear or translog functional forms. The OLS estimation yielded results that ranged widely from significant to insignificant for the respective variables. Some of the variables were lagged to obtain better t-values and appropriate signs. Accordingly, the rainfall variable was lagged by one month as this ensured that the two sets of data corresponded by monthly reporting, the price variables were lagged in order to capture the assumption that consumers change their responsiveness over time thereby allowing comparison of both long-run and short-run price elasticities of demand. The goodness of fit of each equation varied and some were limited by the extent to which the data is aggregated. The Durban-Watsin test was carried out on some of the variables to test for serial correlation and indicated that the degree to which serial correlation became problematic varied between estimations and it was therefore dealt with on case specific basis.

This chapter reports results of the single equation OLS estimations. Estimations were run for each scale of user within Tshwane and their respective user classes. A fuller discussion on the price elasticities follows after the general models for the different user classes have been discussed.

6.2 Scale A: Agricultural Small-holdings

Agricultural small-holdings are defined by the Tshwane municipality as large plots of land that fall within the residential area. It is expected that many of these small-holdings have boreholes and are characterised as large users of water for outdoor purposes, due to their access to other sources of water it is expected that they may not be as responsive to pricing as initially hypothesised. Scale A users are divided into two classes of use namely, the first 0,2 kilolitres of daily consumption (low category) and more than 0,2 kilolitres of the daily consumption (high category).

6.2.1 Low class users

Table 6-1 shows the results of the OLS regression for low category demand users for agricultural small-holdings. These are users that demand up to 0,2 kilolitres of the daily allowance. The adjusted-R^2 of 88 percent indicated that the variables represented the demand relationship well. The Durban-watson statistic was used to test for serial correlation in this time series regression and indicated that the level of serial correlation between the relevant variables was small. The seasonal dummy variables proved to be statistically insignificant and had the wrong signs, but were retained as they improved the goodness of fit. The temperature coefficient also showed an unexpected negative sign but this may be linked to the fact that Tshwane has a summer rainfall, this increase in rainfall with temperature increases may very well lead to a reduction in outdoor water demand on residential properties such as small-holdings. The short-run average price variable also showed a positive sign instead of a negative sign but this was common for many of the estimations and was explained by the increasing block rate tariff and the fact that consumers are initially unaware of the price to which they are responding and merely consume according to needs. This however changes in the long-run as the sign for the lagged average price variable becomes negative over six months. Consumers respond directly to the marginal price reducing consumption as price increases in both the short and long run, but their responsiveness unexpectedly tends to be greater in the short-run. The data plot (figure 6-1) depicts the relationship between the actual and fitted results of the estimation for low category agricultural small-holding users. The results indicate a relatively good fit.

Table 6-1: Modified Logarithmic OLS demand function for Scale A – Low class users

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	14.07	1.30	10.85	0.00
2	P^*_{APALOW}	α_1	2.85	0.62	4.62	0.00
3	P^*_{MPALOW}	α_2	-3.04	0.38	-8.11	0.00
4	$P^*_{APALOW(-6)}$	α_3	-1.41	0.56	-2.53	0.02
5	$P^*_{MPALOW(-6)}$	α_4	-0.92	0.38	-2.46	0.02
6	$Rainfall_{(-5)}$	α_5	-0.03	0.02	-1.20	0.24
7	Temperature	α_6	-1.15	0.39	-2.96	0.00
8	D1nl	α_7	0.05	0.10	0.46	0.65
9	D2	α_8	0.27	0.14	1.86	0.07
10	D3	α_9	0.30	0.11	2.70	0.01
11	UserA	α_{10}	-	-	-	-
12	Dependent Variable	QALOW		R^2		0.90
13	Mean	8.21		R^2-adjusted		0.88
14	Standard Deviation	0.58		S.E. of regression		0.19
15	Sample size	54		Akaike info criterion		-0.27
16	Error Sum of Squares	1.67		Durbin-watson		1.89

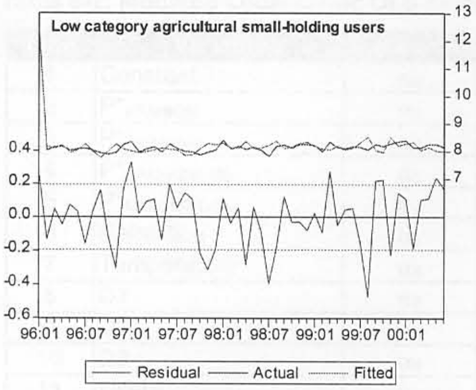

Figure 6-1: Low class users for agricultural small-holdings

6.2.2 High class users

Table 6-2 shows the results of the OLS regression for high category demand users for agricultural small-holdings. These are users that demand more than the first 0,2 kilolitres of the daily allowance. The adjusted-R^2 of 26 percent indicated that the variables represented the demand relationship poorly. The price coefficients showed expected signs except for the short run average price coefficient which was positive, once again this may be explained by the increasing block rate pricing system. The rainfall coefficient showed a negative sign, which was expected but was poorly significant, while temperature was highly significant it showed a negative sign. The confusion of signs within the weather variables may be due to the influence of summer rainfall patterns in the region, where increases in temperature are associated with increases in rainfall. The only significant dummy variable was that for summer with a coefficient of 0.32 (2.00 t-statistic), indicating that increases in temperature lead to small increases in the demand for water. The data plot in figure 6-2 represents the above-mentioned relationship graphically.

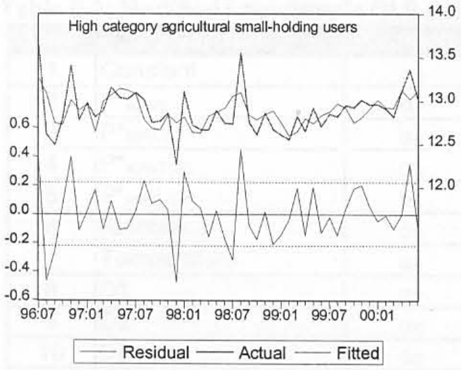

Figure 6-2: High class users for agricultural small-holdings

Table 6-2: Modified Logarithmic OLS demand function for Scale A – High class users

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	18.23	1.66	10.98	0.00
2	$P^*_{APAHIGH}$	α_1	3.05	1.55	1.96	0.06
3	$P^*_{MPAHIGH}$	α_2	-1.53	1.41	-1.08	0.29
4	$P^*_{APAHIGH(-12)}$	α_3	-2.02	1.05	-1.92	0.06
5	$P^*_{MPAHIGH(-12)}$	α_4	-0.16	-0.17	-0.96	0.34
6	$Rainfall_{(-1)}$	α_5	-0.01	-0.03	-0.35	0.73
7	Temperature	α_6	-1.70	0.45	-3.79	0.00
8	D1	α_7	0.11	0.12	0.90	0.37
9	D2	α_8	0.32	0.16	2.00	0.05
10	D3	α_9	0.24	1.53	1.56	0.13
11	UserA	α_{10}	-	-	-	-
12	Dependent Variable	QALOW		R^2		0.40
13	Mean	12.88		R^2-adjusted		0.26
14	Standard Deviation	0.26		S.E. of regression		0.22
15	Sample size	48		Akaike info criterion		0.00
16	Error Sum of Squares	1.86		Durbin-watson		2.30

6.2.3 Aggregated demand across all classes

The aggregated OLS demand function is shown in Table 6-3. This demand function gives the results of for all agricultural small-holdings user classes and categories. Once again, the rainfall and temperature coefficients showed negative signs with rainfall being statistically insignificant and temperature significant. The short run price variables showed unexpected positive signs, while the long run price variables corrected for this and showed negative signs. The short run average price proved to be more statistically significant that the short run marginal price, as users are probably initially unaware of the marginal price. However in the long run users become more responsive to the marginal price for water than the average price for water. However, the adjusted-R^2 of 32 percent indicated a poor goodness of fit.

Table 6-3: Modified Logarithmic OLS demand function for Scale A – Total

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	17.34	1.36	12.71	0.00
2	P^*_{APAT}	α_1	0.79	0.33	2.38	0.02
3	P^*_{MPAT}	α_2	0.17	0.28	0.60	0.55
4	$P^*_{APAT(-6)}$	α_3	-0.36	0.27	-1.32	0.19
5	$P^*_{MPAT(-6)}$	α_4	-0.53	0.18	-2.92	0.00
6	$Rainfall_{(-1)}$	α_5	-0.00	0.02	-0.00	0.99
7	Temperature	α_6	-1.51	0.41	-3.67	0.00
8	D1	α_7	0.10	0.11	0.93	0.36
9	D2	α_8	0.29	0.15	1.97	0.05
10	D3	α_9	0.27	0.13	2.06	0.04
11	UserA	α_{10}	-	-	-	-
12	Dependent Variable	QALOW		R^2		0.43
13	Mean	12.94		R^2-adjusted		0.32
14	Standard Deviation	0.26		S.E. of regression		0.21
15	Sample size	54		Akaike info criterion		-0.07
16	Error Sum of Squares	2.02		Durbin-watson		2.11

The data plot in figure 6-3 represents the above-mentioned relationship graphically.

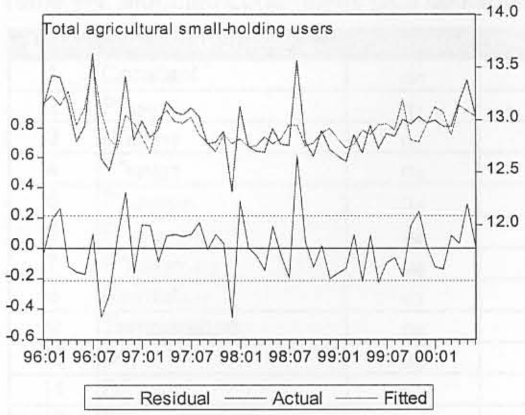

Figure 6-3: Total for agricultural small-holding users

6.3 Scale B: Residential housing

Residential housing incorporates all forms of residence within the Pretoria municipal area except for old age homes and multi-story complexes. This study reports on three categories, namely houses, duets and home-industries.

6.3.1 Aggregated residential demand across all classes

Table 6-4 shows the aggregated OLS demand for residential housing in Pretoria, with an adjusted-R^2 of 52 percent. The estimation for scale B aggregated the user classes identified in Table 5-2. The short run price elasticities proved to be insignificant, but showed the correct signs, while the long run price elasticities were statistically significant but the average price showed an unexpected positive sign. The long run average price variable was lagged for 3 months, while both the marginal price variables were lagged for 12 months. The marginal price variables reflect the change in price from user class 1 to user class 2, and from user class 2 to 3. Both rainfall and temperature were statistically significant and showed the expected signs. The dummy variables were insignificant and only the spring dummy showed the expected sign. The number of users was shown to be statistically significant but had an unexpected negative sign.

Table 6-4: Modified Logarithmic OLS demand function for Scale B – Total

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	26.40	6.36	4.15	0.00
2	P^*_{APBT}	α_1	-0.32	0.33	-0.96	0.34
3	P^*_{MPB1T}	α_2	-0.09	0.20	-0.47	0.64
4	P^*_{MPB2T}	α_3	-	-	-	-
5	$P^*_{APBT(-3)}$	α_4	0.94	0.31	3.01	0.00
6	$P^*_{MPB1T(-12)}$	α_5	-	-	-	-
7	$P^*_{MPB2T(-12)}$	α_6	-0.90	0.35	-2.61	0.01
8	$Rainfall_{(-1)}$	α_7	-0.04	0.01	-3.31	0.00
9	Temperature	α_8	0.77	0.21	3.64	0.00
10	D1	α_9	-0.03	0.08	-0.35	0.73
11	D2	α_{10}	0.05	0.11	0.48	0.63
12	D3	α_{11}	-0.06	0.11	-0.55	0.59
13	UserA	α_{12}	-1.24	0.57	-2.18	0.03
14	Dependent Variable	QB		R^2		0.62
15	Mean	15.05		R^2-adjusted		0.52
16	Standard Deviation	0.15		S.E. of regression		0.10
17	Sample size	48		Akaike info criterion		-1.48
18	Error Sum of Squares	0.41		Durbin-watson		1.79

The data plot in figure 6-4 represents the above-mentioned relationship graphically.

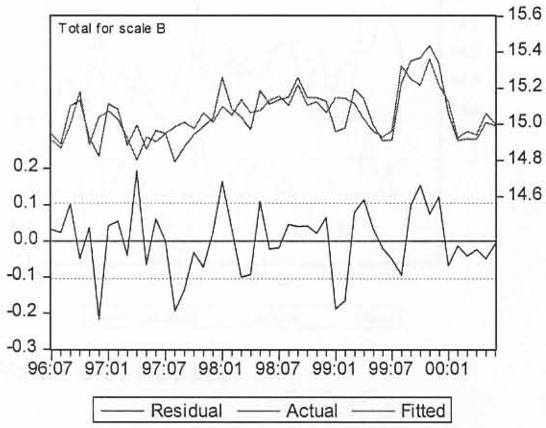

Figure 6-4: Total residential housing

6.3.2 OLS demand for residential users

Table 6-5 shows the demand for residential users. The adjusted-R^2 of 30 percent shows a poor goodness of fit. The short run price variables showed unexpected positive signs and were statistically insignificant. However, when the marginal price variables were lagged by 12 months, the signs became positive and the marginal price for user classes 2 to 3 became statistically significant. This shows that overtime the consumers respond more to marginal price but this is more strongly felt by consumers in the higher user classes. Both the rainfall and maximum temperature coefficients showed the expected signs, but proved to be statistically insignificant.

Table 6-5: Modified Logarithmic OLS demand function for Scale B – Houses

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	13.93	0.45	31.00	0.00
2	P^*_{APBT}	α_1	0.08	0.29	0.27	0.79
3	P^*_{MPB1T}	α_2	0.23	0.16	1.42	0.16
4	P^*_{APB2T}	α_3	0.18	0.46	0.39	0.70
5	$P^*_{APBT(-6)}$	α_4	0.38	0.27	1.40	0.17
6	$P^*_{MPB1T(-12)}$	α_5	-0.01	0.14	-0.10	0.92
7	$P^*_{MPB2T(-12)}$	α_6	-0.67	0.31	-2.18	0.04
8	Rainfall$_{(-1)}$	α_7	-0.00	0.01	-0.92	0.35
9	Temperature	α_8	0.06	0.14	0.47	0.64
10	D1	α_9	-	-	-	-
11	D2	α_{10}	0.14	0.05	2.49	0.02
12	D3	α_{11}	-	-	-	-
13	UserB	α_{12}	-	-	-	-
14	Dependent Variable	QB		R^2		0.43
15	Mean	14.55		R^2-adjusted		0.30
16	Standard Deviation	0.12		S.E. of regression		0.10
17	Sample size	48		Akaike info criterion		-1.64
18	Error Sum of Squares	0.36		Durbin-watson		1.85

The data plot in figure 6-5 represents the above-mentioned relationship graphically.

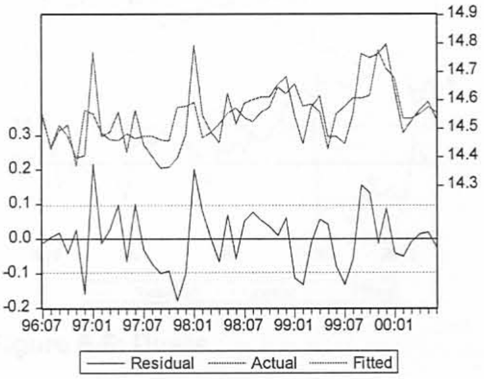

Figure 6-5: Houses

6.3.3 OLS demand for duets

Table 6-6 shows the demand for semi-attached houses. The adjusted-R^2 of 61 percent shows an average goodness of fit. The short-run average price showed an unexpected positive sign, but consumers were shown to be highly responsive to the short-run marginal price. It proved to be highly statistically significant and held a negative sign. In the longer term however, consumers tended to respond more strongly to the average price with it being more statistically significant. Both long-run price variables showed the expected signs, there was however a certain degree of serial correlation within this user category.

Table 6-6: Modified Logarithmic OLS demand function for Scale B - Duets

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	16.27	2.50	6.52	0.00
2	P^*_{APAT}	α_1	4.51	2.54	1.77	0.08
3	P^*_{MPAT}	α_2	-13.48	4.35	-3.10	0.00
4	$P^*_{APAT(-6)}$	α_3	-5.08	2.14	-2.38	0.02
5	$P^*_{MPAT(-6)}$	α_4	-3.59	3.79	-0.95	0.35
6	$Rainfall_{(-1)}$	α_5	-0.03	0.05	-0.62	0.54
7	Temperature	α_6	-0.08	0.75	-0.11	0.92
8	D(SUMMER)	α_7	O.18	0.29	0.64	0.52
9	D2	α_8	-	-	-	-
10	D3	α_9	-	-	-	-
11	UserA	α_{10}	-	-	-	-
12	Dependent Variable	Qduettes		R^2		0.66
13	Mean	10.21		R^2-adjusted		0.61
14	Standard Deviation	0.80		S.E. of regression		0.50
15	Sample size	54		Akaike info criterion		1.58
16	Error Sum of Squares	0.50		Durbin-watson		0.63

The data plot in figure 6-6 represents the above-mentioned relationship graphically.

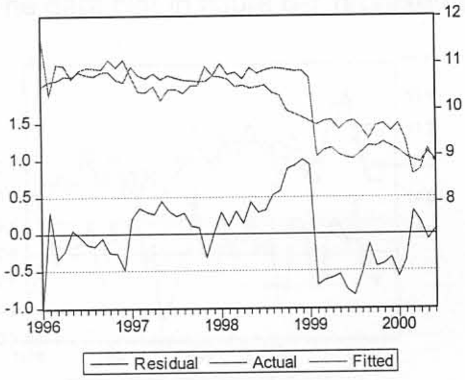

Figure 6-6: Duets

6.3.4 OLS demand for home industries

Table 6-7 shows the demand for home industries. The adjusted-R^2 of 46 percent shows a poor goodness of fit. The short-run marginal price variables showed unexpected positive signs and were statistically insignificant, while the short-run average price variable showed a negative sign but was also statistically insignificant. However, when the marginal price variables were lagged by 6 months, the signs became positive and the marginal price for user classes 2 to 3 was almost statistically significant. The weather variables showed expected signs with only temperature being statistically significant. The user and dummy variables were not statistically significant.

Table 6-7: Modified Logarithmic OLS demand function for Scale B – Home industries

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	21.75	7.86	2.77	0.01
2	P^*_{APAT}	α_1	-0.25	0.33	-0.75	0.46
3	P^*_{MPAT1}	α_2	0.18	0.18	1.01	0.32
4	P^*_{MPAT2}	α_3	0.10	0.54	0.18	0.86
5	$P^*_{APAT(-6)}$	α_4	0.78	0.35	2.23	0.03
6	$P^*_{MPAT1(-6)}$	α_5	-0.28	0.16	-1.70	0.10
7	$P^*_{MPAT2(-6)}$	α_6	-0.16	0.38	-0.42	0.67
8	$Rainfall_{(-1)}$	α_7	-0.02	0.01	-1.13	0.27
9	Temperature	α_8	0.61	0.24	2.57	0.01
10	D1	α_9	0.07	0.09	0.79	0.44
11	D2	α_{10}	-0.05	0.13	-0.39	0.70
12	D3	α_{10}	-0.16	0.11	-1.44	0.16
13	UserA		-0.81	0.70	-1.16	0.25
14	Dependent Variable	Qhomeind		R^2		0.59
15	Mean	15.03		R^2-adjusted		0.46
16	Standard Deviation	0.16		S.E. of regression		0.12
17	Sample size	54		Akaike info criterion		-1.27
18	Error Sum of Squares	0.12		Durbin-watson		1.44

The data plot in figure 6-7 represents the above-mentioned relationship graphically.

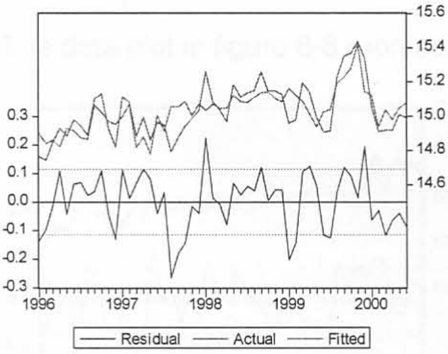

Figure 6-7: Home industries

6.4 Scale C: Duplexes / simplexes

Scale C identifies multi-level housing complexes. Consumers are often metered through one or two points and are billed based on the complex average.

6.4.1 OLS demand for low class users

Table 6-8 shows the OLS demand for consumers of the first 30 percent of daily demand. The adjusted-R^2 of 64 percent indicated that the variables represented the demand relationship fairly well. As this was the first user class, no marginal price variables were included in the estimation. The average price coefficients for both the long-run and the short-run proved to be statistically significant with expected signs. When average price was lagged by 18 months, the consumer proved to be less responsive to price changes than in the short-run, this was unexpected. The weather variables and dummy variables proved to be statistically insignificant and showed both expected and unexpected signs.

Table 6-8: Modified Logarithmic OLS demand function for Scale C – Lifeline rebate

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	28.66	12.41	2.31	0.03
2	P^*_{APCLR}	α_1	-3.14	0.55	-5.74	0.00
3	P^*_{MPCLR}	α_2	-	-	-	-
4	$P^*_{APCLR(-18)}$	α_3	-1.86	0.60	-3.11	0.00
5	$P^*_{MPCLR(-18)}$	α_4	-		-	
6	Rainfall	α_5	-0.01	0.02	-0.31	0.76
7	Temperature	α_6	-0.54	0.33	-1.61	0.12
8	D1	α_7	0.12	0.08	1.51	0.14
9	D2	α_8	0.15	0.12	1.25	0.22
10	D3	α_9	0.11	0.11	1.05	0.29
11	UserC	α_{10}	-1.44	1.66	-0.86	0.40
12	Dependent Variable	QCLR		R^2		0.70
13	Mean	12.49		R^2-adjusted		0.64
14	Standard Deviation	0.24		S.E. of regression		0.15
15	Sample size	42		Akaike info criterion		-0.83
16	Error Sum of Squares	0.70		Durbin-watson		1.75

The data plot in figure 6-8 represents the above-mentioned relationship graphically.

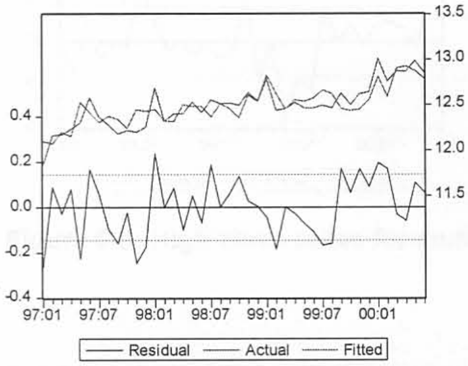

Figure 6-8: Low class users for multi-level residential complexes

6.4.2 OLS demand for high class users

Table 6-9 shows the results of the demand estimation for scale C. The adjusted-R^2 showed an excellent fit of 95 percent. The short run price variables showed the expected signs but were not statistically significant. The long run price variables were lagged for 30 months and the average price showed the correct sign but was also statistically insignificant while the marginal price variable was just statistically significant it did not have the expected sign. Rainfall and the dummy variables were not statistically significant.

Table 6-9: Modified Logarithmic OLS demand function for Scale C – High class users

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	15.49	0.93	16.64	0.00
2	P^*_{APC}	α_1	-0.95	0.72	-1.32	0.20
3	P^*_{MPC}	α_2	-0.28	0.52	-0.53	0.60
4	$P^*_{APC(-30)}$	α_3	-0.77	0.93	-0.83	0.42
5	$P^*_{MPC(-30)}$	α_4	1.11	0.55	2.00	0.06
6	Rainfall	α_5	-0.00	0.01	-0.24	0.82
7	Temperature	α_6	-	-	-	-
8	D1	α_7	0.06	0.06	1.04	0.31
9	D2	α_8	0.02	0.06	0.26	0.80
10	D3	α_9	-0.05	0.05	-0.97	0.34
11	UserC	α_{10}	-	-	-	-
12	Dependent Variable	QC		R^2		0.96
13	Mean	13.63		R^2-adjusted		0.95
14	Standard Deviation	0.37		S.E. of regression		0.08
15	Sample size	30		Akaike info criterion		-1.85
16	Error Sum of Squares	0.15		Durbin-watson		1.83

The data plot in figure 6-9 represents the above-mentioned relationship graphically.

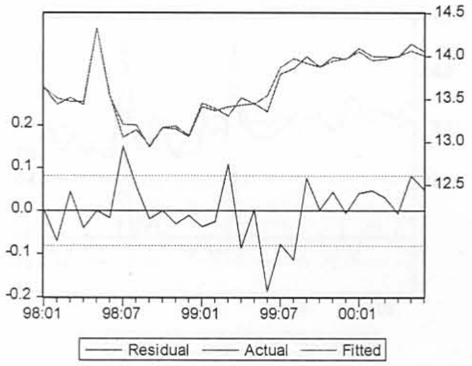

Figure 6-9: High class users for multi-level residential complexes

6.4.3 Aggregated demand for scale C

The aggregated demand for Scale C is shown in Table 6-10, with a poor adjusted-R^2 of 28 percent. The price variables showed expected negative signs and the long run average price variable was statistically significant. The long run price variables were lagged for 8 months. Both the maximum temperature variable and the spring season dummy were statistically significant and showed the correct signs.

Table 6-10: Modified Logarithmic OLS demand function for Scale C – Total

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	-7.09	13.94	-0.51	0.61
2	P^*_{APC}	α_1	0.50	0.67	0.75	0.46
3	P^*_{MPC}	α_2	-0.14	0.10	-1.38	0.18
4	$P^*_{APC(-8)}$	α_3	-2.13	0.65	-3.26	0.00
5	$P^*_{MPC(-8)}$	α_4	-0.01	0.10	-0.10	0.92
6	$Rainfall_{(-1)}$	α_5	-0.01	0.02	-0.45	0.65
7	Temperature	α_6	0.76	0.35	2.15	0.04
8	D1	α_7	-0.23	0.09	-2.35	0.02
9	D2	α_8	-0.21	0.13	-1.66	0.10
10	D3	α_9	-0.22	0.12	-1.85	0.07
11	UserC	α_{10}	2.71	1.88	1.44	0.16
12	Dependent Variable	QC		R^2		0.42
13	Mean	13.53		R^2-adjusted		0.28
14	Standard Deviation	0.21		S.E. of regression		0.18
15	Sample size	52		Akaike info criterion		-0.38
16	Error Sum of Squares	1.36		Durbin-watson		1.94

The data plot in figure 6-10 represents the above-mentioned relationship graphically.

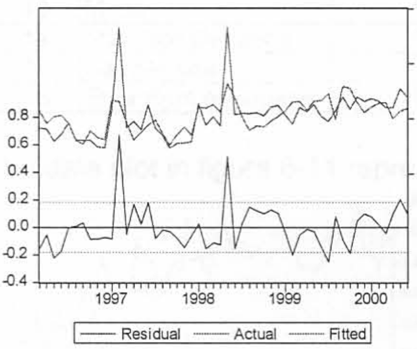

Figure 6-10: Total for multi-level residential complexes

6.5 Scale D: Residential businesses

Due to the data limitations the estimations for small residential businesses could not be run.

6.6 Scale E: Retirement villages

Retirement villages are metered separately in the Pretoria City Council and hence the demand results are recorded below:

6.6.1 OLS demand for low class users

Table 6-11 shows the results for the first 30 percent demanded of daily water consumption. The adjusted-R^2 of 60 percent indicates a fair fit. The price variables all show negative signs except for the short run average price variable that shows a positive sign. This may also be attributed to the increasing block rate system where as one moves to a higher level of consumption one pays more for the water. Rainfall and temperature show the expected signs but are not statistically significant. The dummy and user variables are also not statistically significant and show unexpected signs.

Table 6-11: Modified Logarithmic OLS demand function for Scale E – Low class users

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	8.53	1.11	7.68	0.00
2	P^*_{APELOW}	α_1	1.99	0.58	3.42	0.00
3	P^*_{MPELOW}	α_2	-0.09	0.32	-0.28	0.78
4	$P^*_{APELOW(-9)}$	α_3	-0.51	0.48	-1.05	0.30
5	$P^*_{MPELOW(-9)}$	α_4	-0.62	0.46	-1.35	0.18
6	$Rainfall_{(-1)}$	α_5	-0.01	0.02	-0.89	0.72
7	Temperature	α_6	0.11	0.33	0.34	0.73
8	D1	α_7	-0.10	0.11	-0.89	0.38
9	D2	α_8	-0.06	0.14	-0.42	0.68
10	D3	α_9	-0.01	0.14	-0.10	0.92
11	UserE	α_{10}	-0.02	0.05	-0.3	0.67
12	Dependent Variable	QELOW		R^2		0.68
13	Mean	9.78		R^2-adjusted		0.60
14	Standard Deviation	0.24		S.E. of regression		0.15
15	Sample size	51		Akaike info criterion		-0.78
16	Error Sum of Squares	0.89		Durbin-watson		1.37

The data plot in figure 6-11 represents the above-mentioned relationship graphically.

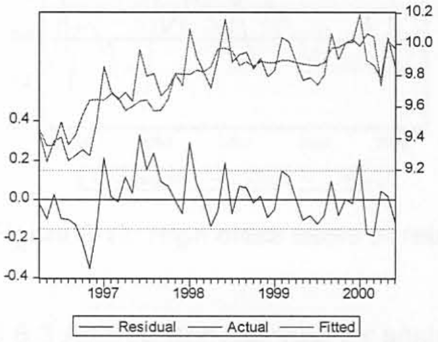

Figure 6-11: Low class users in retirement villages

6.6.2 OLS demand for high class users

Table 6-12 shows the results for water demanded over the first 30 percent of daily water consumption. The adjusted-R^2 of 77 percent indicates a good fit. The price variables all show the expected negative signs except for the short run average price. The short run marginal price variable is statistically significant with a t-value of –2.68. It also indicates that consumers at this level are highly responsive to marginal price changes, with an elasticity of –1.27. Rainfall and maximum temperature show the expected negative and positive signs respectively but are not statistically significant. The seasonal dummy variables and the user variables all show negative signs which is unexpected for users and for autumn and winter as a fall in rainfall should lead to an increase in the demand for water.

Table 6-12: Modified Logarithmic OLS demand function for Scale E – High class users

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	8.04	1.01	7.97	0.00
2	$P^*_{APEHIGH}$	α_1	2.39	1.25	1.92	0.06
3	$P^*_{MPEHIGH}$	α_2	-1.27	0.47	-2.68	0.01
4	$P^*_{APEHIGH(-1)}$	α_3	-0.33	0.28	-0.28	0.78
5	$P^*_{MPEHIGH(-1)}$	α_4	-0.05	0.32	-0.14	0.89
6	$Rainfall_{(-1)}$	α_5	-0.01	0.02	-0.35	0.73
7	Temperature	α_6	0.34	0.28	1.21	0.23
8	D1	α_7	-0.17	0.12	-1.49	0.14
9	D2	α_8	-0.09	0.14	-0.62	0.54
10	D3	α_9	-0.04	0.12	-0.30	0.76
11	UserE	α_{10}	-0.07	0.03	-2.37	0.02
12	Dependent Variable	QEHIGH		R^2		0.80
13	Mean	10.54		R^2-adjusted		0.77
14	Standard Deviation	0.31		S.E. of regression		0.15
15	Sample size	59		Akaike info criterion		-0.78
16	Error Sum of Squares	1.09		Durbin-watson		1.46

The data plot in figure 6-12 represents the above-mentioned relationship graphically.

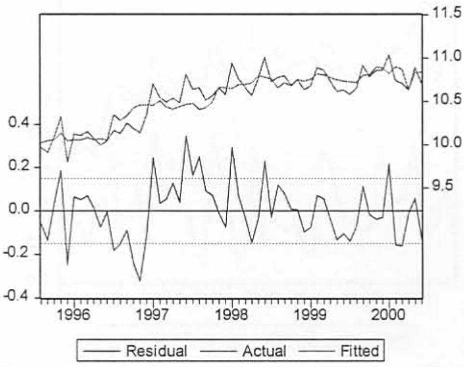

Figure 6-12: High class users at retirement villages

6.6.3 Aggregated demand for scale E

Table 6-13 shows the results for the first 30 percent demanded of daily water consumption. The adjusted-R^2 of 72 percent indicates a good fit. These results are very similar to those recorded in Table 6-12 with all the price variables except for short-run average price showing negative signs. The short-run and average long-run average price variables are statistically significant at 3.78 and –2.97 respectively. Rainfall and temperature show the expected signs but are not statistically significant. The seasonal dummy variables are all insignificant. The user variable however is significant at 5.36 and shows the expected positive sign, indicating that at this demand level the number of water users does directly lead to an increase in the demand for water and this increase is almost unitarily elastic.

Table 6-13: Modified Logarithmic OLS demand function for Scale E - Total

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	5.21	0.87	5.98	0.00
2	P^*_{APE}	α_1	1.94	0.51	3.78	0.00
3	P^*_{MPE}	α_2	-0.34	0.30	-1.13	0.26
4	$P^*_{APE(-12)}$	α_3	-1.14	0.38	-2.97	0.00
5	$P^*_{MPE(-12)}$	α_4	-0.15	0.18	-0.83	0.41
6	Rainfall	α_5	-0.01	0.01	-1.15	0.26
7	Temperature	α_6	0.33	0.23	0.23	0.15
8	D1	α_7	-0.06	0.09	-0.74	0.46
9	D2	α_8	0.07	0.12	0.64	0.53
10	D3	α_9	-0.08	0.10	-0.84	0.41
11	UserE	α_{10}	0.89	0.17	5.36	0.00
12	Dependent Variable	QE		R^2		0.77
13	Mean	11.00		R^2-adjusted		0.72
14	Standard Deviation	0.21		S.E. of regression		0.11
15	Sample size	48		Akaike info criterion		-1.27
16	Error Sum of Squares	0.49		Durbin-watson		2.00

The data plot in figure 6-13 represents the above-mentioned relationship graphically.

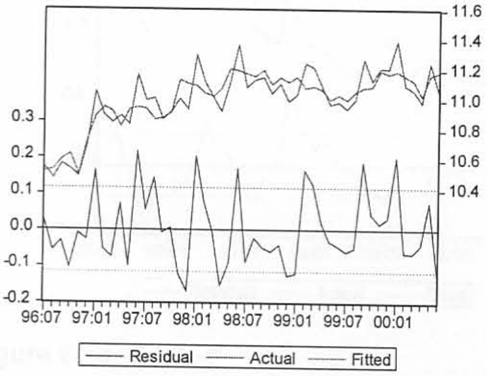

Figure 6-13: Total for retirement villages across all classes

6.7 Scale F: Industry

The accounts for a number of industrial users are recorded by the municipality. One of these accounts is for a large industrial company situated in Centurian. Table 6-14 shows a preliminary estimation for the price elasticity of water demand for industrial users in South Africa based on this user. The adjusted-R^2 of 74 percent indicates a good fit. Only average price was used in this estimation as the industry faces one user charge. Both the short-run and the long-run price variables were statistically significant at –5.24 and –3.50 respectively. The elasticities also indicate that the industry is much more responsive to price changes in the long-run than in the short-run, shifting from an absolute elasticity of 1.61 to 2.18. The rainfall variable was statistically significant and showed the correct sign, while the temperature variable was statistically insignificant and showed the incorrect sign. The seasonal dummy variables were all statistically insignificant.

Table 6-14: Modified Logarithmic OLS demand function for Scale F

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	16.80	2.33	10.70	0.00
2	P^*_{APH}	α_1	-1.61	0.34	-5.24	0.00
3	$P^*_{APH(-24)}$	α_2	-2.18	0.57	-3.50	0.26
4	Rainfall	α_3	-0.03	0.68	-1.16	0.25
5	Temperature	α_4	-0.49	0.03	-1.15	0.00
6	D1	α_5	-0.04	0.15	-0.30	0.76
7	D2	α_6	0.07	0.22	0.30	0.76
8	D3	α_7	-0.01	0.21	-0.05	0.96
9	Dependent Variable	Qindustry		R^2		0.79
10	Mean	10.90		R^2-adjusted		0.74
11	Standard Deviation	0.45		S.E. of regression		0.24
12	Sample size	36		Akaike info criterion		0.13
13	Error Sum of Squares	1.81		Durbin-watson		0.91

The data plot in figure 6-14 represents the above-mentioned relationship graphically.

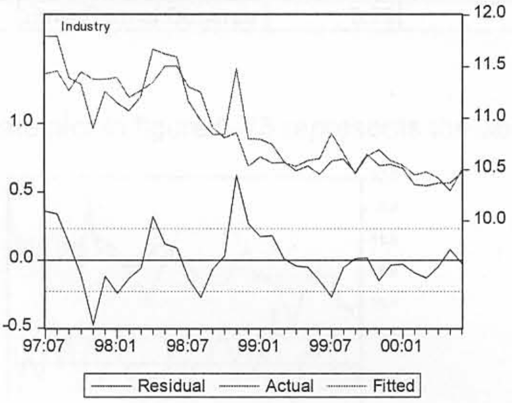

Figure 6-14: Scale F

6.8 Scale G: Attridgeville

6.8.1 OLS demand for high class users

Table 6-15 shows the results for the high class users for Attridgeville. This is the user class level 4, those who use more than 0,1 kiloliters of the daily allowance. The adjusted-R^2 of 50 percent indicates a relatively poor fit. All three marginal price variables and the average price variable were initially incorporated in the estimation, however the removal of the marginal price variables improved the adjusted R^2 and the significance of the average price variables, hence only average prices were incorporated in the model. These both showed the expected sign and the long run average price was statistically significant, it also showed that elasticity of response over time becomes more elastic for this user class. The rainfall, temperature and seasonal dummies were all statistically insignificant and only the spring dummy showed the correct sign.

Table 6-15: Modified Logarithmic OLS demand function for Scale G – High class users

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	1.72	10.76	0.16	0.87
2	P^*_{APELOW}	α_1	-0.42	0.56	-0.74	0.46
3	P^*_{MPELOW}	α_2	-	-	-	-
4	$P^*_{APELOW(-6)}$	α_3	-1.28	0.44	-2.90	0.00
5	$P^*_{MPELOW(-9)}$	α_4	-	-	-	-
6	$Rainfall_{(-1)}$	α_5	0.00	0.02	0.38	0.71
7	Temperature	α_6	0.08	0.24	0.33	0.75
8	D1	α_7	-0.08	0.10	-0.80	0.43
9	D2	α_8	0.10	0.12	0.84	0.40
10	D3	α_9	-0.05	0.11	-0.40	0.70
11	UserG	α_{10}	1.07	0.92	1.17	0.25
12	HH income	α_{11}	0.25	0.71	0.36	0.72
13	Dependent Variable	QELOW		R^2		0.58
14	Mean	11.64		R^2-adjusted		0.50
15	Standard Deviation	0.18		S.E. of regression		0.13
16	Sample size	54		Akaike info criterion		-1.13
17	Error Sum of Squares	0.79		Durbin-watson		1.33

The data plot in figure 6-15 represents the above-mentioned relationship graphically.

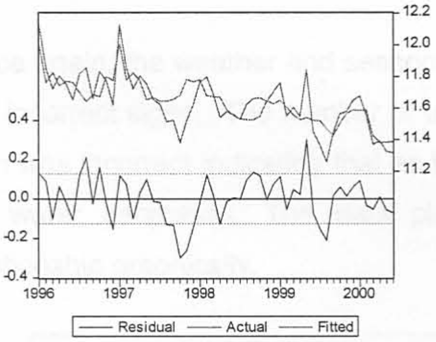

Figure 6-15: High class users for Attridgeville

6.8.2 Aggregated demand across all classes for Attridgeville

Table 6-16 shows the results for the aggregated demanded over all user classes for Attridgeville. The users in this category cover the full range of consumer classes identified in Table 5-2. The adjusted-R^2 of 28 percent represented a poor fit. Both the long-run and short-run average price variables showed positive signs and were statistically insignificant. Two marginal price variables were included in the estimation and the second lagged long-run price variable was statistically significant with a t-statistic of –2.04.

Table 6-16: Modified Logarithmic OLS demand function for Scale G – Total

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	37.67	9.78	3.85	0.00
2	P^*_{APELOW}	α_1	0.42	0.26	1.62	0.11
3	P^*_{MP1}	α_2	-0.06	0.37	-0.16	0.87
4	P^*_{MP2}	α_3	-0.43	0.91	-0.47	0.64
5	P^*_{MP3}	α_4	-	-	-	-
6	$P^*_{AP(-6)}$	α_5	0.22	0.21	1.08	0.29
7	$P^*_{MP1(-6)}$	α_6	-0.07	0.37	-0.20	0.84
8	$P^*_{MP2(-6)}$	α_7	-1.90	0.93	-2.04	0.05
9	$P^*_{MP3(-6)}$	α_8	-	-	-	-
10	$Rainfall_{(-1)}$	α_9	0.02	0.02	0.97	0.33
11	Temperature	α_{10}	0.65	0.31	2.10	0.04
12	D1	α_{11}	0.04	0.12	0.36	0.72
13	D2	α_{12}	-0.12	0.15	-0.82	0.42
14	D3	α_{13}	-0.15	0.14	-1.08	0.29
15	UserG	α_{14}	-2.89	1.01	-2.85	0.00
16	HHI	α_{15}	0.67	0.55	1.22	0.23
17	Dependent Variable	Qattridge		R^2		0.46
18	Mean	12.90		R^2-adjusted		0.28
19	Standard Deviation	0.18		S.E. of regression		0.15
20	Sample size	54		Akaike info criterion		-0.71
20	Error Sum of Squares	0.93		Durbin-watson		1.31

Once again, the weather and seasonal variables were statistically insignificant and showed the incorrect signs. The number of users in Attridgeville was statistically significant but the sign was incorrect indicating that as the number of users of water increase as the demand for water decreases. The data plot in figure 6-16 represents the above-mentioned relationship graphically.

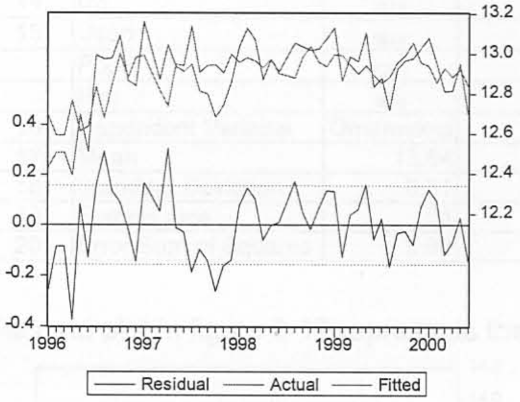

Figure 6-16: Total users across all classes for Attridgeville

6.9 Scale H: Mamelodi

Table 6-17 shows the results for the aggregated demanded over all user classes for Mamelodi. The adjusted-R^2 of 43 percent indicates a poor goodness of fit. All three marginal prices and the average price for Mamelodi were included in the estimation. All the short-run prices showed unexpected positive signs, a result of the increasing block rate tariff consumers face. All the long-run prices showed the expected negative signs. The weather and seasonal variables also proved to be statistically insignificant with rainfall and the spring dummy having the correct negative signs. The user variable was also statistically insignificant but not far from 2.0, the sign was negative. Both a population variable and a household variable were included in this model. The population variable proved to have a t-value of 32.60 but the sign was incorrect. The income variable however was also statistically significant with a t-value of 2.79 and a coefficient of 34.47 indicating that consumers are highly responsive to changes in income, as a 1 unit increase in income will lead to 34.47 unit change in their demand for water.

Table 6-17: Modified Logarithmic OLS demand function for Scale H – Total

Line	Variable	Parameter	Coefficient	Std. Error	T-statistic	Prob.
1	Constant	α_0	512.31	165.91	3.09	0.00
2	P^*_{APELOW}	α_1	0.76	0.49	1.54	0.13
3	P^*_{MP1}	α_2	15.17	5.33	2.84	0.01
4	P^*_{MP2}	α_3	5.39	4.05	1.33	0.19
5	P^*_{MP3}	α_4	1.42	2.38	0.60	0.55
6	$P^*_{AP(-6)}$	α_5	-0.23	0.42	-0.53	0.60
7	$P^*_{MP1(-4)}$	α_6	-5.69	6.56	-0.87	0.39
8	$P^*_{MP2(-3)}$	α_7	-2.09	3.95	-0.53	0.60
9	$P^*_{MP3(-3)}$	α_8	-1.28	2.52	-0.51	0.61
10	$\text{Rainfall}_{(-1)}$	α_9	-0.00	0.02	-0.09	0.93
11	Temperature	α_{10}	-0.18	0.35	-0.50	0.62
12	D1	α_{11}	-0.04	0.13	-0.28	0.78
13	D2	α_{12}	0.07	0.17	0.43	0.67
14	D3	α_{13}	0.04	0.15	0.24	0.81
15	UserH	α_{14}	-0.71	0.47	-1.52	0.14
	PopH	α_{15}	-95.16	32.60	-2.92	0.00
	HHI	α_{16}	34.47	12.37	2.79	0.01
16	Dependent Variable	Qmamelodi		R^2		0.61
17	Mean	13.54		R^2-adjusted		0.43
18	Standard Deviation	0.21		S.E. of regression		0.16
19	Sample size	54		Akaike info criterion		-0.63
20	Error Sum of Squares	0.90		Durbin-watson		1.85

The data plot in figure 6-17 represents the above-mentioned relationship graphically.

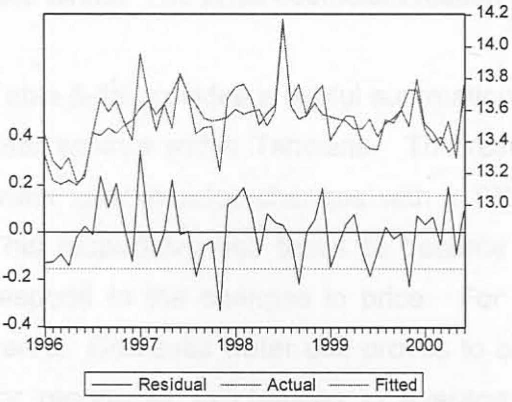

Figure 6-17: Total users across all classes for Mamelodi

6.10 Elasticity results for Tshwane

The elasticity results for all the estimations are tabulated below and allow for comparison over time and between user groups. From the above-mentioned studies, it is evident that for domestic water use rainfall, temperature and seasons have a relatively minor effect on demand. This result is in line with other studies. The number of users in each category proved to be puzzling as it frequently produced a negative sign and was statistically significant. This result is not in line with those of previous studies (section 5-3), which stated that as the number of users increases, the demand for water increases. Only water demanded for old age homes in Pretoria showed a significant response to income changes, with an income elasticity of 0.89 at a five percent significance level, with a t-statistic of 5.36. The population variables behaved as expected and concurred with the results of the other studies. Only a few of the estimations incorporated income variables which also proved to be statistically significant on average and indicated that an increase in income for any user group in turn increases the demand for water.

6.10.1 Price elasticities of demand for Tshwane

The price variables varied widely in terms of statistical significance and sign. On average, the average price variable tended to support the increasing block rate premise in the SR, indicating that as demand increases price also increases because consumers are moving into the next consumption class. In the LR this tended to change and people responded more directly to the price by decreasing demand as it increased. The marginal price variables were valuable as economists are interested in these prices. They also tended on average to encourage demand to move downwards as they increased. The trend in all the studies that lead to a positive sign for many of the average price coefficients is consistent with other urban water demand studies and is congruent with increasing block rate tariffs. The price coefficient results for all the studies are outlined in table 6-18.

Table 6-19 provides a useful summation of the different elasticities of demand for different user sectors within Tshwane. The results indicate that industry is the most responsive water user to price changes with a SR elasticity of -1.79 and a LR elasticity of –2.04. This responsiveness tends to become even more elastic as the user is given time to respond to the changes in price. For this study the time period for adjustment was 2 years. Domestic water use proves to be the least elastic of all users at –0.32 in the SR, for responses to changes in average price. Interestingly, domestic users are more responsive than agricultural small-holding users in the LR, when response comparisons are made between marginal price responses.

Table 6-18: Price elasticities of demand calculated from the various estimation results for the Logarithmic specifications[16].

		Short run				Long run				
Line	E (q_i / p_j)	P_{AP}	P_{MP1}	P_{MP2}	P_{MP3}	P_{AP}	P_{MP1}	P_{MP2}	P_{MP3}	Source
1	$Q_{\text{agriculture – low}}$	2.85 (0.62)	-3.04 (0.38)	-	-	-1.41 (0.56)	-0.92 (0.38)	-	-	Table 6-1
2	$Q_{\text{agriculture – high}}$	3.05 (1.54)	-1.54 (1.93)	-	-	-2.02 (1.93)	-0.16 (0.97)	-	-	Table 6-2
3	$Q_{\text{total agriculture}}$	0.79 (0.33)	0.17 (0.28)	-	-	-0.36 (0.27)	-0.53 0.18)	-	-	Table 6-3
4	$Q_{\text{total – domestic}}$	-0.32 (0.33)	-0.09 (0.20)	-	-	0.94 (0.31)	-	-0.90 (0.35)	-	Table 6-4
5	Q_{houses}	0.08 (0.29)	0.23 (0.16)	0.18 (0.46)	-	0.38 (0.27)	-0.01 (0.14)	-0.67 (0.31)	-	Table 6-5
6	Q_{duets}	4.51 (2.54)	-13.48 (4.35)	-	-	-3.59 (3.79)	-3.59 (3.79)	-	-	Table 6-6
7	$Q_{\text{home industries}}$	-0.25 (0.33)	0.18 (0.18)	0.10 (0.54)	-	0.78 (0.35)	-0.28 (0.16)	-0.16 (0.38)	-	Table 6-7
8	$Q_{\text{duplexes – low}}$	-3.14 (0.55)	-	-	-	-1.86 (0.12)	-	-	-	Table 6-8
9	$Q_{\text{duplexes – high}}$	-0.95 (0.72)	-0.28 (0.52)	-	-	-0.77 (0.93)	1.11 (0.55)	-	-	Table 6-9
10	$Q_{\text{total duplexes}}$	0.50 (0.67)	-0.14 (0.10)	-	-	-2.13 (0.65)	-0.01 (0.10)	-	-	Table 6-10
11	$Q_{\text{old age homes – low}}$	1.99 (0.58)	-0.09 (0.32)	-	-	-0.51 (0.48)	-0.62 (0.46)	-	-	Table 6-11
12	$Q_{\text{old age homes – high}}$	2.39 (1.25)	-1.27 (0.47)	-	-	-0.33 (0.28)	-0.05 (0.32)	-	-	Table 6-12
13	$Q_{\text{old age homes – total}}$	1.94 (0.51)	-0.34 (0.30)	-	-	-1.14 (0.38)	-0.15 (0.18)	-	-	Table 6-13
14	Q_{industry}	-1.79 (0.34)	-	-	-	-2.04 (0.42)	-	-	-	Table 6-14
15	$Q_{\text{attridgeville – high}}$	-0.42 (0.56)	-	-	-	-1.28 (0.44)	-	-	-	Table 6-15
16	$Q_{\text{attridgeville – total}}$	0.42 (0.26)	-0.06 (0.37)	-0.43 (0.91)	-	0.22 (0.21)	-0.07 (0.37)	-1.90 (0.93)	-	Table 6-16
17	$Q_{\text{mamelodi – total}}$	0.76 (0.49)	15.17 (5.33)	5.40 (4.05)	1.42 (2.38)	-0.23 (0.42)	-5.67 (6.56)	-2.09 (3.95)	-1.28 (2.52)	Table 6-17

When comparing the water use for domestic consumers in Pretoria central and Mamelodi, it becomes evident that in the long-run both users respond more elastically to marginal price changes. With a clear indication that lower income users respond almost twice as strongly to price changes with a long run marginal price elasticity of –2.09 compared to that for Pretoria of –0.90. The results are highly dependent on the user class selected hence elasticities for some of the other models outlined in the table above, show different results.

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[16] All bracketed numbers are t-values

Table 6-19: Comparative sectoral price elasticities of demand for selected studies and prices

		Short run				Long-run				
Line	**E (q_i / p_j)**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**P_{MP3}**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**P_{MP3}**	**Source**
1	$Q_{agriculture}$	-	-	-	-	-0.36	-0.53	-	-	Table 6-3
2	$Q_{domestic}$	-0.32	-0.09	-	-	-	-	-0.90	-	Table 6-4
3	$Q_{industry}$	-1.79	-	-	-	-2.04	-	-	-	Table 6-14
4	$Q_{mamelodi}$	-	-	-	-	-0.23	-5.67	-2.09	-1.28	Table 6-17

This comparative table can be further disaggregated to reflect the differences between industrial / commercial water use and domestic water use across the case study and the international literature.

Table 6-20 shows the price elasticities of demand for industrial or commercial use. The SR price elasticities range between –0.5 in Massachusetts, USA to –1.79 in Tshwane, RSA. Interestingly, the Tshwane elasticities are considerably more elastic than those observed in the USA studies, this may be indicative of the nature of the industries being compared. None of the other studies estimated LR price elasticities of demand and hence it was not possible to provide a comparative judgement on the LR responsiveness of these consumers.

Table 6-20: Comparative Industrial and commercial price elasticities of demand

		Short run				Long-run				
Study	**E (q_i / p_j)**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**P_{MP3}**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**P_{MP3}**	**Year**
King	$Q_{industry}$	-1.79	-	-	-	-2.04	-	-	-	2002
Turnovsky	$Q_{industry}$	-0.5	-	-	-	-	-	-	-	1969
Lynn et al.	$Q_{commercial}$	-0.17	-	-	-	-	-	-	-	1978

Table 6-21 shows the comparative domestic indoor price elasticities of demand across the case study, national studies and the international literature. The indoor price elasticities of demand for Tshwane were comparatively similar to those of other studies. They were however considerably less elastic than the Dockel (1973) study and higher than the Veck and Bill (1999) study. The LR price elasticity of demand for Attridgeville (lower income group user) also showed a significant change from a relatively inelastic response to a more elastic response of –1.28. The SR marginal price elasticities of demand were also similar for all the respective studies but were surprisingly less elastic than the average price responses, this may be attributable to the fact that in the SR most users are unaware of the impacts of marginal price on their bills. For Mamelodi, the LR responses to marginal price changed dramatically, indicating that a lower income levels, over time, responses to the marginal price of water become extremely elastic, ranging from between –2.09 to –5.67.

Table 6-21: Comparative domestic (indoor) price elasticities of demand

		Short run			Long-run			
Study	**E (q_i / p_j)**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**Year**
King	$Q_{domestic}$	-0.32	-0.09	-	-	-	-0.90	2002
King	$Q_{mamelodi}$	-	-	-	-0.23	-5.67	-2.09	2002
King	$Q_{attridgeville}$	-0.42	-	-	-1.28	-	-	2002
Dockel	$Q_{witwatersrand}$	-0.63 to-0.84	-	-	-	-	-	1973
Veck & Bill	Q_{indoor}	-0.12 to-0.14	-	-	-	-	-	2000
Gibbs	$Q_{domestic}$	-0.62	-0.51	-	-	-	-	1978
Nieswiadomy	$Q_{domestic}$	-0.22 to -0.6	-0.1to-0.17	-	-	-	-	1992
Howe et al.	$Q_{domestic}$	-0.23	-	-	-	-	-	1967
Turnovsky	$Q_{domestic}$	-0.3	-	-	-	-	-	1969
Wong	$Q_{domestic}$	-0.26 to-0.82	-	-	-	-	-	1972
Young	$Q_{domestic}$	-0.63 to-0.41	-	-	-	-	-	1973
Katzman	$Q_{domestic}$	-0.1 to -0.2	-	-	-	-	-	1977
Foster & Beattie	$Q_{domestic}$	-0.35 to-0.76	-	-	-	-	-	1979
Agthe & Billings	$Q_{domestic}$	-0.12 to-0.22	-	-	-0.27to-0.49	-	-	1980
Carver & Boland	$Q_{domestic}$	-0.1	-	-	-0.2 to –0.7		-	1980
Howe	$Q_{domestic}$	-0.52 to-0.86	-	-	-	-	-	1982
Hewitt&Hanemann	$Q_{domestic}$	-0.57 to-0.63	-	-	-	-	-	1995
Hansen	$Q_{domestic}$	-0.003	-	-	-	-	-	1996
Thomas & Syme	$Q_{domestic}$	-0.2	-	-	-	-	-	1988

Table 6-22 shows the comparative outdoor domestic price elasticities of demand for Tshwane, Alberton and Thokoza, and the United States of America. The SR price elasticities of demand for the Tshwane outdoor (agricultural small-holdings) use were not included in this comparative table as they showed a positive sign, indicating discrepancies in the data. The LR marginal and average price elasticities were however, included. In the longer run it appears that outdoor users for Tshwane adjust there consumption patterns, becoming more elastic in their responses to price changes. They become less elastic in their responses to marginal price changes, however, this may be indicative of their ignorance regarding the marginal prices and the fact that they merely respond directly to the average price reported on their monthly water bills. The studies by Veck and Bill (2000) and Howe and Linaweaver (1967) are included in the table below for illustrative purposes only, it must however be noted that outdoor water use defined in these studies does not equate to what is referred to as outdoor water use for Tshwane, namely water use for agricultural small-holdings. This explains some of the differences in the elasticities shown below.

Table 6-22: Comparative domestic (outdoor) price elasticities of demand

		Short run			Long-run			
Study	**E (q_i / p_j)**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**P_{AP}**	**P_{MP1}**	**P_{MP2}**	**Yea**
King	$Q_{agriculture-high}$	-	-1.54	-	-2.02	-0.16	-	2002
King	$Q_{agriculture}$	-	-	-	-0.36	-0.53	-	2002
Veck & Bill	$Q_{outdoor}$	-0.19 to-0.47	-	-	-	-	-	2000
Howe et al.	$Q_{sprinkling}$	-0.16 to -0.7	-	-	-	-	-	1967

6.10.2 Income elasticities for Tshwane

Table 6-23 shows the comparative income price elasticities for Tshwane, Alberton and Thokoza, and the other water demand studies reviewed in Table 6-18. The income elasticities for Tshwane were only estimated for Attridgeville and Mamelodi as disaggregated data for the other user categories was not available. The results indicate that consumers in Attridgeville are relatively inelastic when it comes to changes in income due to the nature of the good being demanded – water is regarded as a necessity. The sign is positive, reiterating that as income increases the demand for water also increases. The range of elasticities for Attridgeville also correspond well with those reported in the national and international literature despite being insignificant. The income elasticity for Mamelodi was however significant, showed the expected positive sign, but fell greatly outside the ranges reported in the literature review. This indicated that water consumers in Mamelodi are extremely elastic in their responses to changes in income and their associated consumption of water.

Table 6-23: Comparative income elasticities of demand

Study	$E(q_i / p_j)$	Income	t-statistic	Source
King	$Q_{\text{attridgeville – high}}$	0.25	0.36	Table 6-15
King	$Q_{\text{attridgeville – total}}$	0.67	1.22	Table 6-16
King	$Q_{\text{mamelodi – total}}$	34.47	2.79	Table 6-17
Veck and Bill	$Q_{\text{household water demand}}$	-0.11	-	2000
Average other studies	$Q_{\text{household water demanded}}$	0.2 to 1.03	-	1986 to 2000

6.10.3 Meteorological elasticities for Tshwane

Unlike Hansen (1996), the meteorological variables had an insignificant impact on the household and the industrial demand for water in Tshwane. The estimated coefficients were relatively inconsistent with the accuracy of their signs and failed to be significant at a five percent level of significance. It was expected that the rainfall variables and the spring and summer dummy variables would show negative signs, as rainfall increases demand for water is expected to decrease. Tshwane also falls within the summer rainfall belt within South Africa and hence, higher temperatures are often associated with higher rainfall.

6.11 Relating price elasticities of demand for water to water management decision-making

Relevant to any water resources pricing analyst is the responsiveness of consumers at different consumer classes to changes in the prices of the resource. The results outlined in sections 6-2 through to section 6-9 indicate that pricing can be used to manage demand for water resources in South Africa and that different consumer classes show different levels of responses to price changes. These findings are discussed further in chapter 7. What is however interesting at this point is the fact that the derived elasticities from the above-mentioned models in conjunction with the average prices and quantities of water demanded can be used to determine the willingness to pay by the different consumer classes for water supplied at certain levels, as an extension to merely evaluating their levels of responsiveness. The willingness to pay or marginal values for water for different user categories can be used by pricing decision-makers to inform tariff levels to which consumers will then respond.

The willingness by consumers to make trade-offs is what determines the marginal value. For marketed goods, this willingness refers to the willingness to pay a particular monetary price for a good (Khan, 1998). Gibbons (1986), defines the total value for water resources as the maximum amount a user would be willing to pay for the resource. Where market transactions are observed, market-clearing prices will represent the value of the respective resource and where markets do not exist, market-like transactions can indicate the amount that consumers are willing to pay for a particular resource and thereby provide a measure of at least a lower bound value. For water, pure[17] markets rarely exist, hence alternative approaches to determining value need to be considered. Three approaches provide more complete demand information they are: the formal demand curve, the production function and the financial budget. Marginal values for water use may be obtained from consumer or producer water demand functions provided sufficient information on prices and quantities is available for demand modelling. Marginal physical product information can be determined from production functions for water, multiplying this with the price of the good produced will in turn yield a marginal product value. Lastly, information on the financial budget of a productive process can be used to determine the maximum economic return to economic inputs of that process once the share of total product value to the input such as water, is known (Gibbons, 1986). Valuing water use is also dependent on the definition of use as it has a number of dimensions namely, quantity, quality, timing and location. Use values need to be adjusted for instream and

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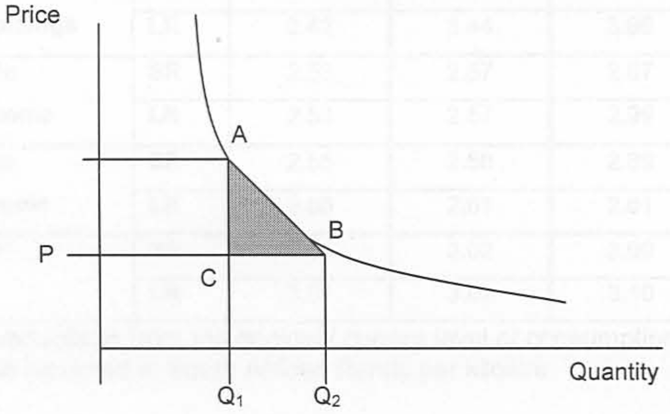
[17] Pure markets here, refers to markets that are free of transaction costs and imperfect information with well-defined property rights.

offstream users to reflect the location and the implied costs of transportation. Quality aspects need to be accounted for along with the nature of the quantity used, as water can be withdrawn but not consumed. Hence, the trade-offs between competition and complementarity of users arise (Gibbons, 1986). Furthermore, the different measures of value produce different results of value, which are not always directly comparable. Average and marginal values differ widely as do long-run and short-run values. Where constant returns to scale are exhibited however, these differences may be equated and usually reflect long-run values (Gibbons, 1986). Marginal values may be used to influence policy efficacy and are determined for the Tshwane study for four of the aggregated user categories, namely, agricultural small-holdings demand, residential demand at high income and low income levels and industrial demand.

The approach taken here was based on the methodology outlined by Gibbons (1986) from the report by Young *et al.* (1972), whereby the area under the estimated demand curves is found by taking the integral of the curve, identified as Q_1Q_2AB in figure 6-18 below. This represents the amount that a consumer will actually pay for water including the consumer surplus ABC. The consumer surplus however represents the amount that a consumer would actually be willing to pay for the marginal increase in water supplied from Q_1 to Q_2. It therefore represents the marginal value of an incremental increase in water to that consumer. Where a single point (Q_2, p) on the curve is known and the elasticity, ε, is constant over the incremental increase from Q_1 to Q_2, the area under the demand curve may be calculated using the formula above the line in equation 6-1 (Gibbons, 1986 and Young *et al.*, 1972). This area is then divided by the incremental change in quantity and the price is subtracted to leave us with the marginal value for water.

Figure 6-18: Marginal value for water based on the consumer surplus



$$Marginal\ value\ water = \left[\frac{\dfrac{P * Q_2^x}{1-x}\left(\dfrac{Q_2}{Q_2^x} - \dfrac{Q_1}{Q_1^x}\right)}{(Q_2 - Q_1)}\right] - P \quad \text{where } x = \frac{1}{|\varepsilon|} \qquad (6\text{-}1)$$

The average price for residential water use in Tshwane ranges from 1.81 rands per kilolitre for old age homes to 3.42 rands per kilolitre for agricultural small-holdings. Mamelodi, Attridgeville and Pretoria face similar charges for household water use ranging from 1.22 R/kl at the lower consumption levels to 2.55 R/kl on average and 3.15 R/kl at the highest consumer class. The resultant marginal values for water in Tshwane based on the current level of use, a 1 percent, a 10 percent, a 25 percent and a 50 percent level of reduction from the current levels of water demanded are depicted in figure 6-19 to figure 6-22 below.

Figure 6-19 indicates that agricultural small-holding users are willing to pay R5.21 per kilolitre for a fifty percent increase in the availability of water in the short-run, an increase of 52 percent from the price currently being paid, and R9.35 per kilolitre in the long –run, an increase of 173 percent. Figure 6-20 indicates that residential users at the high-income level are willing to pay R3.59 per kilolitre for a fifty percent increase in availability in the short-run and R8.01 in the long-run. The results of the price changes for the other reductions and user categories are shown in Table 6-24, below.

Table 6-24: Willingness to pay for increments in water availability by four user groups

Users	Time	Reductions in water availability from current levels*				
		Current	1%	10%	25%	50%
		Price**	Price	Price	Price	Price
Agricultural small-holdings	SR	3.42	3.44	3.65	4.09	5.21
	LR	3.42	3.44	3.96	5.14	9.35
Domestic High-income	SR	2.53	2.57	2.67	2.94	3.59
	LR	2.53	2.57	2.99	4.01	8.01
Domestic Low-income	SR	2.55	2.58	2.89	3.60	5.93
	LR	2.55	2.61	2.61	5.10	15.36
Industry	SR	3.01	3.02	3.09	3.52	3.52
	LR	3.01	3.02	3.10	3.59	3.59

*Water reductions from the original / current level of consumption in kilolitres
**Price is recorded in South African Rands per kilolitre

The marginal value estimates indicate that:

- Consumers are responsive to reductions in water availability,
- Consumers are willing to pay more in incrementally larger amounts for greater percentage increases in availability of water demanded,
- Consumers are willing to pay higher prices in the longer run for water,
- Industry is the least willing to pay incrementally more for water, this may be indicative of their ability to change their water consumption patterns through technology changes,
- The low income residential users are the most willing to pay for incrementally more water and this may be attributed to their use of water for basic needs.

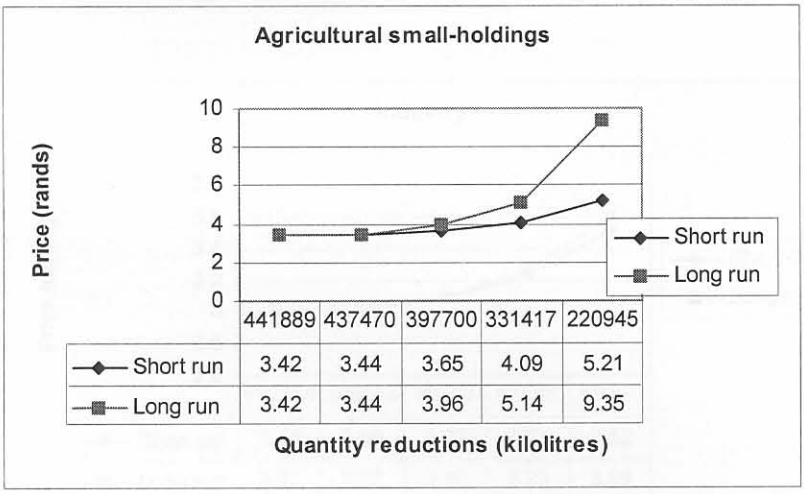


Figure 6-19: Marginal values for water for agricultural small-holdings users

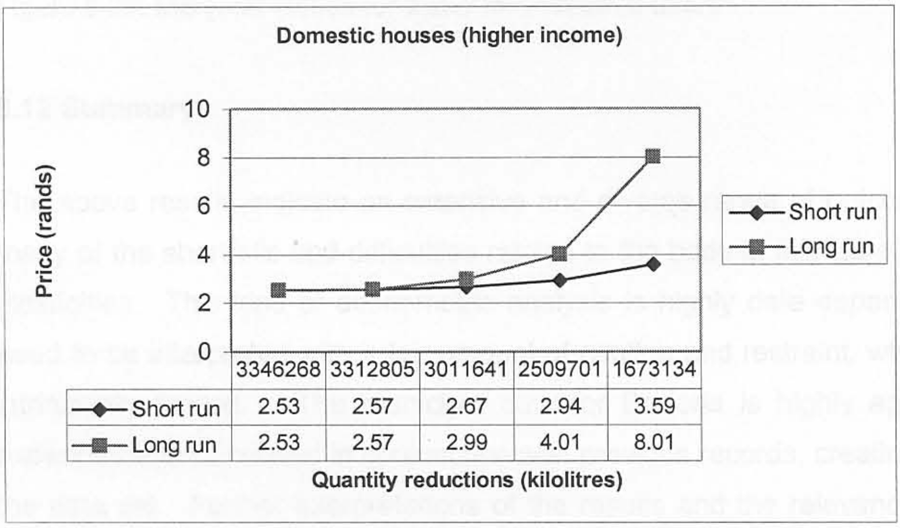


Figure 6-20: Marginal values for water for residential users at higher income levels

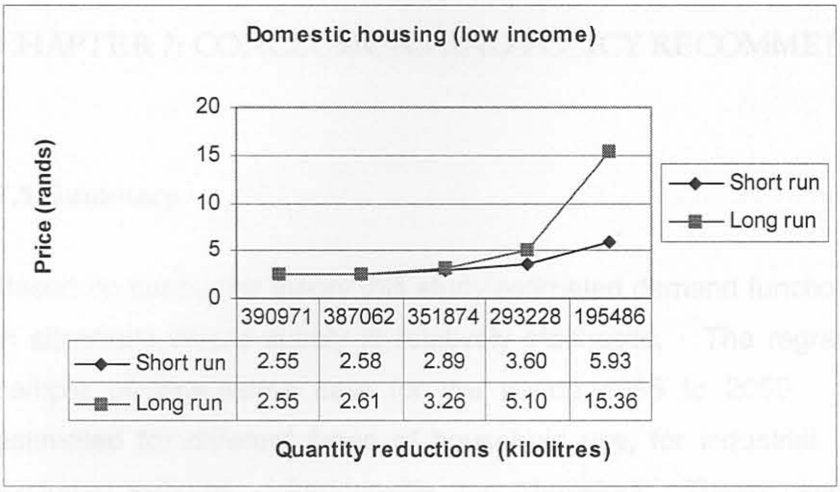


Figure 6-21: Marginal values for water for residential users at lower income levels

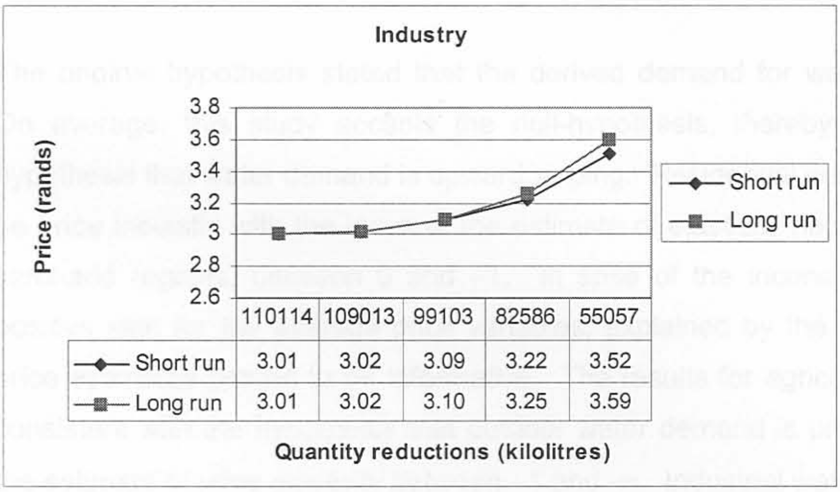


Figure 6-22: Marginal values for water for industrial users

6.12 Summary

The above results indicate an extensive and diverse range of outcomes, consistent with many of the shortfalls and difficulties related to the body of literature on water pricing and elasticities. This kind of econometric analysis is highly data dependent and the results need to be interpreted with a fair amount of caution and restraint, where the base data is intrinsically flawed. The municipal data for Pretoria is highly aggregated and water expenditure is calculated in conjunction with previous records, creating an inherent bias in the data set. Further interpretations of the results and the relevance of these results to the Tshwane municipality is given in chapter seven.

CHAPTER 7: CONCLUSIONS AND POLICY RECOMMENDATIONS

7.1 Summary

Based on consumer theory this study estimated demand functions for water for Tshwane, in situations where supply is relatively stochastic. The regressions were applied to a sample of time-series data for the period 1995 to 2000. Separate functions were estimated for different types of household use, for industrial use and for two formerly excluded suburbs – Attridgeville and Mamelodi. These users were selected so that comparisons could be made between different user classes as well as between different income groups.

The original hypothesis stated that the derived demand for water is downward sloping. On average, this study accepts the null-hypothesis, thereby rejecting the alternative hypothesis that water demand is upward sloping. Residential water demand did appear to be price inelastic with the locus of the estimate of elasticity near to that found for arid or semi-arid regions, between 0 and –1. In spite of the inconsistencies evidenced by a positive sign for the average price variables, explained by the data limitations, marginal price estimates proved to be informative. The results for agricultural smallholdings were consistent with the hypothesis that outdoor water demand is price elastic with a locus of the estimate of price elasticity between –1 and -∞. Industrial water demand also proved to be more price elastic with a locus of the estimate of price elasticity closer to –2 and not the originally hypothesised -1.

The definition of price in previous demand studies has lead to numerous inconsistencies. Some of the studies have used the average price paid for all units consumed while others have used marginal price, the price of the last unit (Gibbs, 1978; Turnovsky, 1969). A significant difference in the results based on price specification is often observed. Theoretically, the cost of the last unit of water consumed or marginal price is the appropriate measure of price, giving the added advantage of enabling the analysis of consumer response to changes in the price structure.

These responses should also be two fold, responding not only to tariff changes based on cost recovery estimates but ideally to water tariffs incorporating the opportunity costs and externalities associated with water use such as concerns of social equity, quality variations and drought relief or flood protection.

Results in this study are suggestive, rather than conclusive, as is the case in the majority of quantitative estimation studies (Gibbs, 1978). Further work is needed to improve the accuracy of data. However, some initial conclusions can be drawn to inform the Tshwane Municipality on the feasibility of using tariffs and prices to influence water demand, as follows:

- The outdoor (agricultural small-holdings) average price elasticities of demand are elastic, indicating that a one unit increase in price will result in a reduction of water demanded by twice that, provided these adjustments to price are medium to long term, allowing for consumer responsiveness.

- The outdoor (agricultural small-holdings) marginal price elasticities also indicated that consumers in this category were responsive to price changes, but interestingly, the greatest adjustments are made in the short-run and consumers become less elastic in the long-run indicating that water managers need to redress the pricing strategy over time as consumers reduce their levels of adjustment.

- Household responsiveness to price falls into a number of categories, and tends to be quite location and accommodation type specific when determining relevant tariff and pricing structures. In general pricing can be used to influence household water demand to some extent, in the long-run as consumers tend to become more aware of their billing structures and the level of household expenditure attributed to water use. In the short-term consumers are relatively unresponsive to price changes at this level, with the lower income level consumers situated in Attridgeville and Mamelodi proving to be marginally more elastic to price changes than many of the other household consumption categories.

- Of all the consumer classes, the industrial consumer proved to be the most highly responsive user category to price changes. These responses becoming even more strongly elastic in the long-run. As a result, water demand savings can be made by implementing pricing strategies at this user level.

These results are to a large extent inconclusive due to the nature of the estimation errors and data limitations, indicating that substantial improvement in specification and estimation could be achieved if the data set was expanded in terms of size and detail on prices and quantities related o water consumption. Furthermore, recent developments in the literature have identified a number of ways in which to account for the shortfalls inherent in a block rate pricing structure and to adjust for the positive signs on the price variables (Nauges,2002; Strand and Walker, 2002). In light of these developments, it is advised that the models in this study be refined using the techniques from these recent findings.

7.2 Conclusions and Recommendations

This study was intended to build on international literature and be a platform from which water decision-makers could engage in the debate around water-pricing and tariff-setting in South Africa. From the outset, the availability and nature of the data dictated the outcomes and associated biases.

The impending urgency to address the rapidly expanding constraints to economic development and quality of life through access to dwindling supplies of water resources is currently driving research institutions, academia, water management institutes such as water boards and the Governmental Departments to find innovative and effective solutions. These solutions need to be informed, at least, at a first-best "guesstimate" level.

The quality of results is partly ascribed to the quality of the data on which it is based. In the water sector, substantially more detail is required for useful analyses and where this detailed data exists, it is important that analysts gain access to it – for the benefit of water management in the country. Where data is blatantly absent, concerted efforts need to be taken by the respective departments (local, provincial and national) to ensure that this data is recorded and disseminated to the relevant analysts, by conducting surveys, ensuring clearly defined reporting, and encouraging efficient information management.

Possible improvements in existing available data are:

- Larger samples
- Time-series data or panel data (balanced or unbalanced)
- Marginal costs of water, valued at market prices or opportunity cost
- Records of climatic conditions at all levels of analysis (rainfall, temperatures)
- Fluctuations within precipitation levels due to extreme weather events such as droughts

- Uniform quality ratings of water resources
- Household level income data including aggregations at a local, provincial and national level
- Population data at a micro and macro-economic level

Furthermore, the implementation of water demand management within South Africa requires further investigation into the following areas:

- Information on water use in each sector
- Institutional frameworks and water authorities, so that the correct levels in the management structure may be targeted for implementation and monitoring
- Consumer behaviour and incentives
- The marginal value of water
- Forecasting water demand
- Strategies for service provision
- Policies on water rights, cost recovery, pricing investment, private sector roles, environmental protection and restoration
- River basin activity and relationships
- Interrelations between water sources
- Integrated basin and watershed management

Supply management is no longer the only mechanism for achieving water security. Demand management is becoming an increasingly more viable option for wise water resource allocations. It is therefore, imperative that economic demand studies provide decision-makers with the most relevant and useful information, re-iterating the need for good quality water data and informed decision-making.

Econometric estimations, as performed here, provide testable hypotheses about consumer behaviour, and a basis from which demand elasticities for water can be computed for policy simulation and analysis, thus enabling the water sector in South Africa to be proactive in its response to international and local water demand pressures.

The use of pricing as one of the tools available under the umbrella of water demand management options is recommended in conjunction with water awareness programmes if reductions in water use are to be promoted. A multi-part tariff structure in line with the responsiveness of different consumer classes is recommended for the most effective results. The achievement of clarity and understanding on water values across these classes is also encouraged as a means to determining the baselines from which pricing strategies can be implemented. The willingness to pay by consumers for certain levels of water availability can also be used to inform decision-makers around pricing policies during periods of drought or impending water stress. It is therefore recommended that this study serve merely as a guide to emphasise the advantageous implications of effective and efficient pricing policies where water resources are becoming inherently scarcer. Continued and fervent research around these issues is further encouraged.

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APPENDICES

APPENDIX 1

POLICY CRITERIA FOR WATER RESOURCES MANAGEMENT

Efficacy: The implemented policy must be capable of or successful in producing an intended result, thereby ensuring the continued optimal management of the resource.

Economic efficiency: Fundamental to the understanding of welfare economics, are the themes of efficiency and equity - the latter is discussed below. Efficiency is defined by Collins (1986) as "functioning or producing effectively with the least waste of effort". In terms of economics, this approach is captured through allocative efficiency, which determines the extent to which the economy is using its scarce resources and provides a value judgement on whether they are being squandered or used sustainably. Resource allocations are not only carried out through market mechanisms but are also determined by the feasibility of the allocations, the technology and resources available to the economy, the tastes and preferences of consumers and ultimately the value they place on these tastes and preferences. An allocation is deemed pareto-efficient for a given set of consumer tastes, resources and technologies when it is no longer possible to move to a better level of allocation without making someone worse-off. However, such an allocation is rarely determined without some form of intervention where markets either do not exist or are imperfect, evident in the case of fresh water resources (Begg et. al, 1991; Teitenberg, 1992). Two forms of efficiency are evident, first-best efficiency and second-best efficiency. The former refers to the situation where all distortions within a market are removed and full efficiency is achieved, the later refers to the imposition of other distortions in order to counter balance existing distortions that cannot be removed (Begg et. al, 1991). For the allocation of scarce resources such as water, efficiency in allocation is highly dependent on the type or sources of water being drawn. For surface water, in the absence of storage, the challenge is to allocate renewable water among different competing users. Future supplies are dependent more on natural processes such as precipitation, run-off, evaporation and temperature than on existing demand patterns and intergenerational effects are not as significant. However, for non-renewable groundwater allocations, intergenerational effects are far more consequential and allocations over time become part of the efficiency criteria. Restrictions on transfers of water, water pricing structures, common property problems and the nature of the resource have lead to inefficient water allocations (Tietenberg, 1991).

Equity: Equity refers to the fairness of distribution of goods between people. Horizontal equity is the identical treatment of identical people and vertical equity is the different treatment of different people in order to redress these innate differences (Begg et. al, 1991). The principles of equity, equity between like users and equity principles aimed at addressing the imbalances of marginalised areas increasingly govern water resources policy.

Environmental impacts: Any policy measures implemented for water management must in turn minimise damage to the related environment. This refers to supply-side and demand-side management approaches.

Fiscal impacts: In order for a water resources policy to remain feasible it needs to take into consideration all fiscal impacts. Returns on investment, long-term financial sustainability, the availability of current capital to service the policy measure, and tax and subsidy effects are all factors that will determine the continued success of a water management policy.

Political and public acceptability: Intrinsic to the nature of water policy measures is the stability of the political and public climate as well as the willingness of decision-making authorities and the general public to accept and implement the proposed suggestions.

Sustainability: Water resources will not be sustained if the governing policies are not sustainable. By sustainable, I am referring to economic sustainability that depends intrinsically on environmental sustainability. Water resources will be sustainable while the resources are used in a manner that ensures intergenerational growth. This means use in a way that ensures the resource is not depleted or polluted to a point beyond which it cannot be regenerated or replenished.

Administrative feasibility: Capacity within government, water management associations and water user structures needs to exist in order to carry out the administrative responsibilities of the water policies.

APPENDIX 2

THE SOUTHERN AFRICA WATER DEMAND MANAGEMENT DECLARATION,

March 1999

We the participants of the first Southern Africa Water Demand Management Conference, do hereby adopt the following vision:

The efficient, equitable and sustainable integrated approach where demand-based options precede the traditional supply options at National and Southern African Regional levels.

We recognise that with current demand patterns, Southern Africa will not be able to reconcile demand and supply by 2025 and that in many areas in the region there is already considerable competition for the meagre resources. This is in the wake of the considerable challenge to meet the needs of a large unserviced population and a high growth rate of a relatively young peoples.

We also realise that there is considerable potential for increased water availability through more efficient allocation and use patterns. This will be guided by but not limited to:

- *Economic efficiency*
- *Equity of access*
- *Environmental protection*
- *Governance based on maximum participation, responsibility and accountability*
- *The adoption of Water Demand Management into regional policy for shared water resources*

We therefore resolve to:

Advance the cause of Water Demand Management throughout Southern Africa and undertake to advocate for the inclusion of Water Demand Management as an essential component of development planning.

Agreed in March 1999 in Johannesburg, South Africa

Source: Reproduced from Goldblatt et al, 2000.

APPENDIX 3

FUNCTIONAL FORMS

1. Utility theory

Some of the most commonly used functional forms that represent preferences in utility theory are the following:

1.1 preferences for perfect substitutes

$u (x1, x2) \quad = \quad ax1 + bx2$

1.2 preferences for perfect compliments

$u (x1, x2) \quad = \quad \min \{ ax1, bx2 \}$

1.3 Cobb-douglas

$u (x1, x2) \quad = \quad x1c \ x2d$

2. Engel curves

The most commonly used engel functions are the following:

Curve	Mathematical formula	Income elasticity
Linear	$Q = a + b y$	$\eta = (q - a) / q$
Double logarithmic	$\ln q = a + b \ln y$	$\eta = b$
Semilogarithmic	$Q = a + b \ln y$	$\eta = b / q$
Logarithmic reciprical	$\mathrm{Ln}\, q = a - b / y$	$\eta = b / y$

(Sadoulet and De Janvry,1995)