DESIGNING A WELFARE MAXIMISING WATER TARIFF FOR DURBAN WITH RAMSEY PRICING PRINCIPLES

Submitted by

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Declaration

I hereby certify that this dissertation was independently written by me. No material was used other than that referred to. Sources directly quoted and ideas used, including figures, tables and drawings have been correctly denoted. Those not otherwise indicated belong to the author

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Abstract

A water supply tariff is a powerful water management tool that can be used to promote a number of economic, environmental and social-political objectives. In South Africa, increasing block tariffs are deemed to satisfy the domestic tariff regulations of the Water Services Act of 1997. The regulations require that the tariff supports the viability and sustainability of water supply services to the poor and discourages wasteful or inefficient water use.

The application of increasing block tariff structures presents a number of problems. The main issue being the size and price of each block. Ramsey pricing proposes that consumer welfare is maximised when the mark-up in price above cost of a good is proportional to the price elasticity of demand of the good. This principle was applied in setting the block prices of an increasing block water tariff. The sizes of the blocks were based on the average water consumption of low, middle and high income consumers.

The water demand characteristic of low, middle and high income households from a sample of domestic consumers in Durban were investigated. The water demand functions and price elasticity of demand for the three groups were estimated using econometric models. Two tariff structures based on Ramsey pricing principles were proposed and compared with the current increasing block tariff applied in Durban.

The frequency distribution of demand of each of the three consumer groups were applied in a model to ensure the proposed tariffs met a certain revenue target. The water demand functions of each of the consumer groups were used to model how the proposed tariff structures impacted consumer surplus and water demand.

The investigation found that increasing block tariffs designed with Ramsey pricing principles have a positive impact on social welfare, provide sufficient revenue for water service providers and support the conservation of water resources.

Table of contents

List of tables

List of figures

1 Introduction

A water supply tariff is a powerful management tool that can used to promote a number of economic, environmental and social-political objectives. A well-designed water tariff can achieve some objectives simultaneously, for example economic and environmental objectives, while in other cases tradeoffs may have to be made (Boland and Whittington, 2000, p220). Water service providers need tools and guidance in order to propose tariffs that are welfare maximizing, meet economic requirements and do not harm the environment.

The primary objective of tariff setting for municipal officials is to secure sufficient revenue from water sales to cover the cost of providing the service. The primary objective of policymakers, especially in developing countries with extreme income inequalities, is that basic water services are affordable. Increasing block tariff pricing structures are the main approach used in developing countries to address problems of unequal income distribution and provide fair access to water (Dinar and Subramanian, 1997, p4). In South Africa, increasing block tariffs are deemed to satisfy the domestic tariff regulations under the Water Services Act of 1997 (DWAF, 2001, section 6(2))

The application of increasing block tariffs structures presents a number of problems. The main issue being the size and price of each block. Policymakers must set the size of the first block equal to a household's essential water needs in order to successfully target the poor. Politicians will want this block to be as large as possible, however each increment in the size of this first block will raise the price of subsequent blocks.

On the 14th of February 2001, the Minister of Water Affairs and Forestry announced that local government in South Africa would provide 6 000 litres of free water per household per month (Kasrils, 2001, paragraphs 1-3). He further added that free basic water is to be funded using a combination of the equitable share grant fund from national government and internal cross-subsidies from appropriately structured water tariffs in a manner which best reflects the specific situation in the respective local government area.

In July 2003, at the celebration in Durban of the nine millionth person to receive safe water since 1994, Minister Kasrils made a promise to the people of South Africa (Kasrils, 2003, paragraph 6). His words were

> *...The promise for the next ten years is to move up the ladder, from communal tap to the convenience and dignity of having water in people's own yards with each household having its own toilet and even, in time, hot and cold running water inside the house enjoyed by many more of our people. That's what I mean by climbing the water ladder. As we climb the ladder, so our people will experience better and better standards of supply and services...*

It is clear from the regulations and the Ministers speeches that the national government expects municipalities to structure the water tariff so that it is possible for poor households to receive 6 kL per month of free basic water, and be able to afford higher levels of service in future. The increasing block tariff must cross subsidise the cost of consumption of low income households by taxing the consumption of high income households. The tariff must still ensure that sufficient revenue is collected over and above the equitable share subsidy to ensure the sustainability of water services. This poses the question; what is the optimum increasing block tariff structure that will allow fair and equitable cross subsidisation while maintaining revenue sufficiency?

Welfare economics proposes that the solution to this problem is based on maximizing the sum of Marshallian Consumer Surplus for different income groups subject to the tariff schedule. Ramsey's 1927 contribution to the theory of taxation provides us with a solution to this problem of welfare maximization under a revenue cost constraint (Ramsey, 1927, pg 47). Bös demonstrates how the Ramsey formula reduces to an inverse elasticity rule for public utilities applying peak load pricing (Bös, 1981, pg 56). In this case the ratio of price-cost margins of the tariff blocks is equal to the reciprocal ratio of the price elasticities of demand.

Ramsey pricing appears to be a simple yet robust method of achieving welfare maximization under a revenue cost constraint. Is this really the case?

Setting water supply tariffs will remain a contentious issue. It is hoped that with sound econometric principles, a tariff can be developed that maximizes welfare, meets economic requirements and does not harm the environment. The tariff should then be politically and sociably acceptable and enable the national government to fulfil its promise of affordable water for all its people.

1.1 Objectives

The purpose of the research in this dissertation was to investigate if a tariff based on Ramsey pricing principles resulted in an increase in welfare for the domestic water consumers of Durban. The specific objectives of the research were:

- Establish the water demand characteristics of domestic households in Durban.
- Estimate the demand function and associated demand price elasticity of low, middle and high income households.
- Estimate the marginal cost of domestic water supply
- Propose an increasing block tariff based on Ramsey pricing principles
- Compare the impact on welfare of the proposed tariff against that of the current tariff by measuring the change in consumer surplus.
- Present the findings and make recommendations to the Durban city council regarding the application of Ramsey pricing principles in setting water tariffs.

1.2 Structure of the dissertation

The literature pertaining to the application of Ramsey pricing is reviewed in **Chapter 2**. In **Chapter 3** the methodology adopted in the research is presented. The existing domestic consumer market was segmented into low, middle and high income households. A tariff block was created for each segment by targeting the size and price of each block according to the consumers revealed demands. Data for the research was collected from the municipal billing system for representative samples of the three consumer groups. The research estimated the water demand schedule and associated water demand price elasticity of each consumer group from the historical records of monthly water consumption between 1997 and 2003. The research also determined the cost of providing the service using data from the annual financial statements of the ring-fenced municipal water service provider and regional bulk water supplier. A new tariff is proposed using Ramsey pricing principles. The findings are presented in **Chapter 4**.

The dissertation compares the proposed increasing block tariff structure with the existing tariff structure of Durban in **Chapter 5**, and concludes with some recommendations on tariff setting for Durban. **Chapter 6** presents recommendations for further research on this subject.

2 Literature review

The literature review covers a number of distinct subjects that provide a framework for the study. An introduction to the micro economic theory of water demand is given in **Section 2.1**. This section highlights some of the challenges in estimating the price elasticity of demand. **Section 2.2** reviews a number of previous studies on the price elasticity of domestic water demand. A general discussion on the theory and practice of water tariff setting is then presented in **Section 2.3**. The review continues with a discussion on the application of welfare economics in tariff setting in **Section 2.4**. The literature review concludes with an introduction to the principles of the Ramsey pricing formula in **Section 2.5**.

2.1 An introduction to the micro economic theory of water demand

Economists use the term utility to refer to the expected pleasure or satisfaction a person obtains from the consumption of goods and services. In the case of a single good or service, total utility refers to the amount of satisfaction obtained from the person's entire consumption of the product. Marginal utility refers to the amount of satisfaction received from consuming the last or marginal unit of product. It is obvious that the satisfaction received from the first glass of water consumed on a day to satisfy thirst is much higher than the third glass. This is also known as the law of diminishing marginal utility. It is also possible for the marginal utility to be negative, for example a person will obtain negative utility from trying to consume a tenth glass of water in a short time period.

How much a person is prepared to pay for a product depends on how much satisfaction they expect to receive from its consumption. As it has been established that a person receives increasingly smaller increments of utility from each additional unit of consumption, it can also be assumed that they will be willing to pay progressively less for each additional unit of the product. In other words, as the marginal utility of a good diminishes, so does their willingness to pay. This law of demand is illustrated in **Figure 2.1** with the downward sloping demand curve. Simply put; consumers are generally willing to buy larger quantities of a good at lower prices.

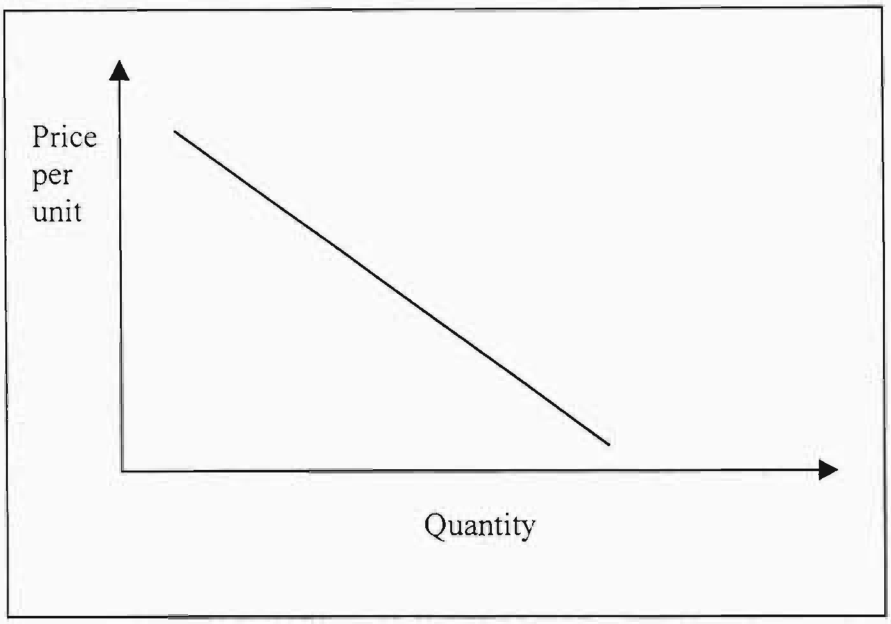

Figure 2.1: An individuals theoretical demand curve for goods and services

The response of consumers to a change in price is measured by the price elasticity of demand. More specifically, the price elasticity of demand (ε) refers to the percentage change in quantity demanded (Q) divided by the percentage change in price (P). (Lipsey et al, 1990, pg 75).

$$\textit{price elasticity } \varepsilon = \frac{\Delta\%Q}{\Delta\%P}$$

The more responsive the change in demand is to change in price, the greater the elasticity of demand.

An important determinant of elasticity is the price of the good in relation to the consumer's income. A small % increase in the price of an expensive good will have a larger impact on a consumers budget than a small % increase in the price of a less expensive good. Likewise the increase in price of a basic good will have a larger impact on a poor household in comparison to a rich household.

The actual measurement and application of the price elasticity of demand presents a number of challenges. The first requirement is an accurate estimate of the consumer demand function. Assuming this information is available, the estimated elasticity will depend on the shape of the demand curve, the range over which the elasticity is measured, the time span covered in measuring the elasticity response, and the method of calculation adopted.

Problems with the shape of the demand curve are illustrated by the straight-line curve shown in **Figure 2.2**.

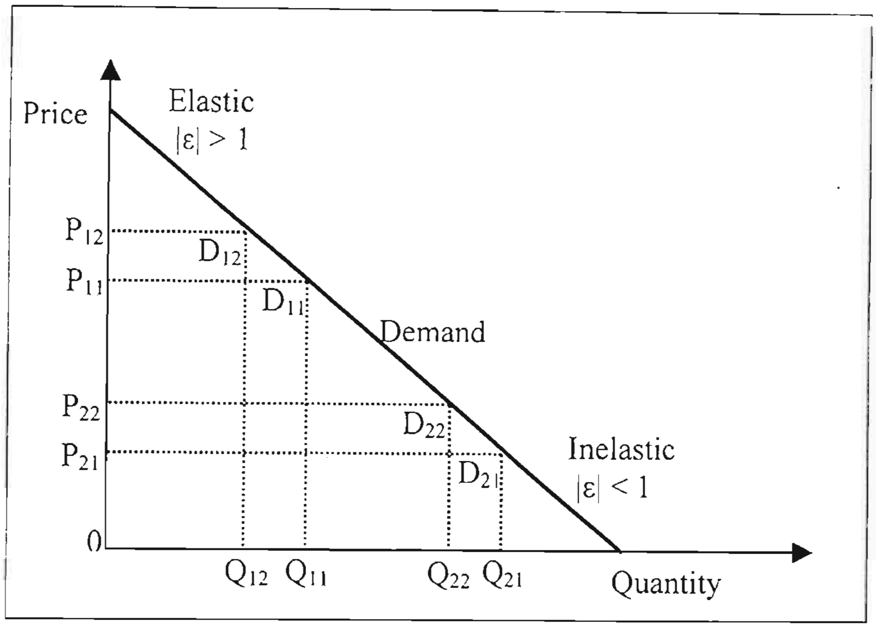

Figure 2.2: Changes in elasticity along a straight-line demand curve

On this straight line curve an increase in price, example from P_{11} to P_{12} or from P_{21} to P_{22} results in a similar decrease in demand from Q_{11} to Q_{12} or from Q_{21} to Q_{22} respectably. Assuming the difference in price P_{11} - P_{12} is equal to P_{21} - P_{22}, then the difference in quantity Q_{11} - Q_{12} is equal to Q_{21} - Q_{22}. However the percentage change in price $(P_{12}-P_{11})/P_{11}$ is much smaller than the percentage change in price $(P_{22}-P_{21})/P_{21}$. Similarly the percentage change in demand $(D_{12}-D_{11})/D_{11}$ is much greater than the percentage change in demand $(D_{22}-D_{21})/D_{21}$. As a result the observed movement of D_{11} to D_{12} will result in a much larger estimate of the absolute value of price elasticity than a similar movement from D_{21} to D_{22}. Note that the difference in these observed price elasticities diminishes over the range as the demand curve becomes more convex.

In the previous discussion the average change in demand in response to a change in price over a specific range was measured. This is known as the arc elasticity. Theoretical discussions use the point elasticity, the responsiveness of demand to price at a specific point on the demand curve. From its definition, the point elasticity is the derivative of the demand curve function at a specific point (Lipsey et al, 1990, pg 93). Obviously the calculated value of the arc elasticity will be closer to the point elasticity as the length of the arc reduces.

The price elasticity of demand is also affected by time. The short run elasticity of demand measures how consumers change their purchase decision immediately after a change in price has been announced. In the case of commodities like water, electricity and petrol, the demand is relatively inelastic in the short term, as these items are considered essential. In the long run consumers will change their habits and invest in more efficient water appliances like dual flush toilets, low flow showers and water efficient washing machines. The long run elasticity of demand measures the consumer response to price after sufficient time has passed to assume that all consumer adjustments to the changed price have occurred.

Assume there are three consumers all subject to the same water tariff. Each consumer will have a unique curve describing their change in demand in response to tariff increases. Since high income households will tend to purchase more water at the same price in comparison to low income households, the demand curve for the high income household will be further from the origin than the low income households. Lipsey et al (1990, pg 91) demonstrates that in the case of parallel straight-line curves, the one furtherest away from the origin is less elastic than the one closer to the origin at the same price.

Making an accurate estimate of price elasticity for a consumer under the conditions described previously is challenging and easily criticised. An important consideration when comparing price elasticities is that the demand curves have similar shape and the elasticity is measured over the same range, during the same time period and by the same method.

A popular empirical method used by economists to deal with the challenge is the double log regression (more commonly called a log linear regression by economists). The log of demand is plotted against the log of price, transforming the curve into an apparently straight line. Simple linear regression can then be estimated using the ordinary least squares (OLS) routine. An attractive feature of the log-linear model is that the price elasticity of demand is given directly by the coefficient of the price variable. The elasticity is also constant throughout the price range. (Gujarati, 1999, pg 242).

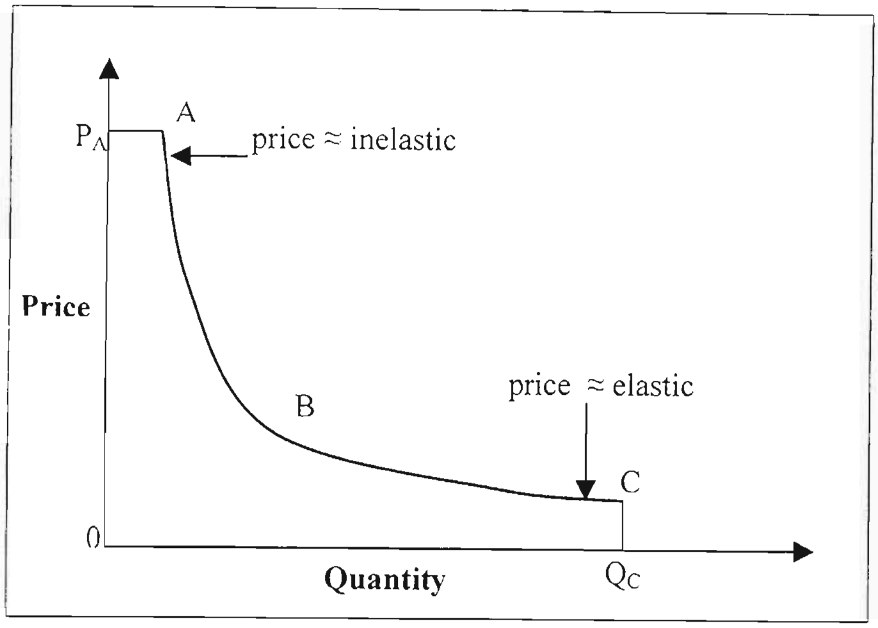

Figure 2.3: Theoretical demand curve for a domestic water consumer

Figure 2.3 shows a theoretical demand curve for a typical domestic water consumer (adapted from Stephenson, 1999). As price increases from point B to point A, consumers will reduce demand, only using water for high value used like drinking, cooking and basic health and hygiene. Consumer demand will tend to be price inelastic at the limit. As price rises beyond point A on the curve, the public water supply will be too expensive and the consumer will find alternative lower cost water sources. Price elasticity is infinite at this point. High-income households will invest in rainwater harvesting or groundwater extraction infrastructure. Low income households will obtain water from unprotected rivers and streams, considering the cost of poor health to be lower than the cost of the public water supply.

If the price decreases from point B to point C then the consumer will make more use of water for low value uses or luxury consumption. For example washing cars, filling swimming pools and watering exotic gardens. Price elasticity in this range tends to be more price elastic. At point C the current capacity of available water resources and supply infrastructure is exhausted and no further demand is possible, even with a drop in price. Price elasticity is zero at this point.

It is interesting to note that in **Figure 2.2** the calculated elasticity for low demand and high price tended to be elastic, whereas in **Figure 2.3** the same range is intuitively believed to be inelastic. If the demand curve for water at low demand and high price was vertical, the calculated elasticity of demand would be 0, or perfectly inelastic. This once again emphasises the importance of the shape of the demand curve

2.2 Price elasticity studies

There is an extensive list of price elasticity of water demand studies that have been conducted in the developed world, in particular for urban and agricultural water use in the USA. Most research has focussed on the methodology adopted and very little attention is given to the application of the findings. There is also a wide range of results emanating from the research. Approximately one third of estimates of elasticity are in the range 0 to - 0.3, a further third in the range - 0.3 to - 0.6 and the balance are above -0.6. Ten percent of estimates show that demand is elastic and greater than 1.0 (Eberhard, 1999a, pg 83).

A comprehensive study by Nieswiadomy and Molina in 1988 applied ordinary least squares (OLS), instrumental variables (IV), and two stage least squares (2SLS) methodologies to estimate water demand using micro data for a sample of 104 domestic consumers faced with and increasing block tariff structure in Denton, Texas. They found that the price elasticity of demand was not significantly different from zero, and concluded that this was due to the fact that the cost of water was insignificant being less than 1 % of the households budget (Nieswiadomy and Molina, 1988, pg 10).

In South Africa, Döckel (1973) attempted to determine the price elasticity of water demand for different water user categories in 27 municipalities between the period 1960 to 1970. Döckel used aggregated annual consumption data and an average price for water. In some cases there was insufficient time series data available to analyse consumption of specific demand categories, for example in the black townships. Döckel found that the price elasticity of water demand for white households was –0.69. He also found that income was not a significant factor in determining water demand (Döckel 1973, pg 20)

A more recent study in South Africa by Veck and Bill (2000) found the price elasticity of low, middle and high income households to be –0.14, -0.17 and –0.19 respectively for Alberton and Thokoza using a contingent valuation approach (Veck and Bill, 2000, pg 5.9). Note that they found the elasticity of demand for low income households to be lower than that of higher income households. The elasticity was estimated according to the responses given by households when asked how much water they would consume if the price of water were to increase or decrease significantly. This approach is criticised because it cannot be assumed that behavioural intention and actual behaviour are the same thing. However contingent valuation experiments have proved useful in willingness to pay surveys where econometric data are not available but is only valid as a short run estimate of the price elasticity of water demand. Veck and Bill also developed an econometric model for Alberton using annual consumption data between 1986 and 1993. They estimated the medium to long run price elasticity of water demand to be –0.73, however they suggested that the model was not useful because of the poor diagnostic statistics obtained (Veck and Bill, 2000, pg 6.5).

In an application of Ramsey pricing in Kerala, India, Pushpangadan and Murugan found the price elasticity of demand for water in the 10 – 30 kL/month block to be –0.7. Their cross sectional study was based on observing the change in demand of 355 households before and after a tariff rate change. Floor area was used as a proxy for income and the impact of weather on demand was not taken into account. (Pushpangadan and Murugan, 1998, pg 18)

It is clear from the studies presented here that both data quality and estimation method have a significant impact on the results of price elasticity studies.

2.3 *The theory and practice of tariff setting*

A water tariff is a set of rules and regulations regarding prices, charges, and taxes that water utilities use to collect revenue. The tariff is a powerful and versatile management tool that officials can use to promote a number of objectives, although there are often tradeoffs between objectives (Boland and Whittington, 2000, p220). Tariff setting is inevitably a political process raising a lot of controversy in trying to find the correct balance between the different objectives and the rights and needs of diverse groups. One of the reasons why tariff setting is so controversial is that in many cultures new to institutional water supply, water is seen as natural resource that should be made available free-of-charge. It is not easy to change that vision of free abundant water, even when faced with the reality of water becoming an increasingly scarce resource.

There is also a call from Marxist supporters for the decommodification of water, i.e. remove price altogether as a determinant in the production and consumption of water services (McDonald, 2002, p33). McDonald provides ample criticism of the current cost recovery framework, but unfortunately does not give any clear practical guidelines on how decommodification will work, apart from making decisions based on the notions of shared cultural values, etc. Pape (2002, p183) admits that it is easy to critique current cost recovery case studies but struggles to propose an alternative. For the time being water supply in general will continue to be viewed as a private good with only limited consumption necessary for personal health and hygiene viewed as public goods.

Boland and Whittington (2000, p220-222) state that revenue sufficiency, economic efficiency, income redistribution, and resource conservation are all important objectives of tariff setting. Tariffs need to be equitable and fair or there will be problems with the political and public acceptability of the tariffs. The revenue stability, ease of implementation and the simplicity and transparency of the tariffs are also important considerations.

In a survey of 22 developing and industrialised countries, Dinar and Subramanian (1997) found that countries prioritise different objectives. Some wish to recover costs, some want to transfer income between sectors through cross subsidisation, and others use charges to improve water allocation and water conservation. For urban water supply most countries are replacing flat fees with two part tariffs, a fixed charge and a variable charge, with considerable variation between countries in the design of block rates. Most developing countries and some industrialised countries set charges based on average rather than marginal costs of supply. Only France sets urban water prices based on the long-term incremental costs of supplying water to account for future resource development costs (Dinar and Subramanian, 1997, p4).

Theoretically, in a competitive market, demand and supply determine price, and the price equals marginal cost, therefore marginal cost rate design results in economic efficiency. This occurs when the marginal value to consumers equals the marginal cost of production, and no other quantity of water can increase the net value to society (Hall, 2000, p195). This proposition ignores externalities and the public good aspects of water, as well as the market failure resulting from the natural monopoly of urban water supply.

Marginal cost pricing may also be regressive. If the aggregate consumer demand (including industry, high income and low income households) is used to determine the market price, then poor consumers will pay more for water and purchase less than they would if the market consisted only of low income consumers (Goldblatt, 1999, pg 31). This is illustrated in **Figure 2.4**.

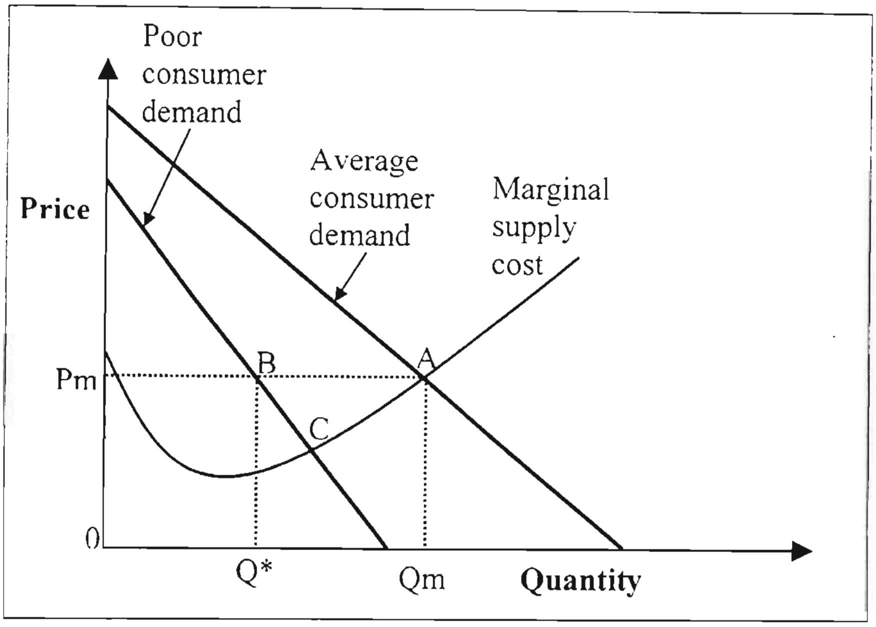

Figure 2.4: Demand and supply curves for an average consumer and a poor consumer (Goldblatt, 1999, pg 31)

In **Figure 2.4**, the efficient market clearing price (Pm) and quantity (Qm) is found at point A, the intersection of the average demand and marginal supply curves. The marginal price Pm will intersect the poor consumers demand curve at point B, resulting in low income households paying price Pm for a quantity of Q*. If the market consisted only of low income households, the efficient market clearing price and quantity will be at point C and poor consumers will pay less for a larger volume of water at its marginal cost. Marginal pricing therefore fails to serve low income households unless the market is differentiated. Remember that the economic efficiency benefits of marginal prices are only applicable at the margin of consumption. Therefore if the market is differentiated and the majority of consumers are exposed to marginal prices at their marginal consumption then we can still achieve the economic efficiency desired by economists.

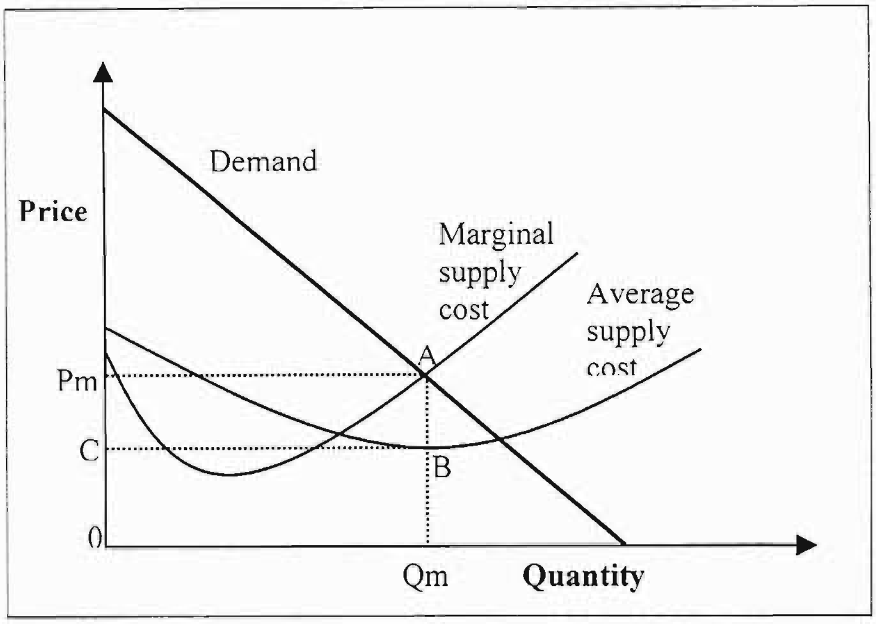

Figure 2.5: Consumer demand and marginal and average supply cost curves. (Stephenson, 1999, pg 116).

Marginal pricing may also result in a producer surplus for the water service provider (Goldblatt, 1999, pg 31). **Figure 2.5** shows the theoretical equilibrium condition between the price and the quantity supplied and demanded for average costing and marginal costing (Stephenson, 1999, pg 116). If the water service provider was to sell all water at the marginal price Pm and the quantity demanded was Qm then economic efficiency will have been achieved. However we must note that the revenue collected at this price [A-Qm-0-Pm] exceeds the costs [B-Qm-0-C] by the area [A-B-C-Pm]. Since a public water service provider may not make a profit this excess revenue is either consumed by inefficient water distribution or becomes available for subsidising consumption for low-income households. If the marginal supply cost curve was below the average supply curve at the point of intersection with the demand curve, then marginal pricing would result in insufficient revenue to cover the cost of supply.

A carefully designed increasing block tariff with the majority of consumers consuming in a block set at the marginal price will achieve economic efficiency while still providing income redistribution for lower income groups consuming in the lower consumption blocks. Hall (2000, pg 195) notes that the calculation of the marginal cost of supply is a complex task. He suggests that the simplest way to approximate the marginal cost is to calculate the incremental cost of the next capital investment in additional water supply capacity. Marginal cost pricing is typically defined by the World Bank as average incremental cost pricing, where the average incremental cost is calculated by dividing the discounted value of future water supply costs by the (similarly discounted) amount of additional water to be produced (Eberhard, 1999a, pg 59).

This discussion on tariff setting concludes with the remark by Eberhard (1999b, pg 25).

> *...A generalised method which can be applied in order to determine the appropriate price structures and tariffs in any specific urban area does not exist and is not desirable... The development of an appropriate pricing policy must be informed by both the national and local specific historical, socio-economic and political-economic contexts... The very real political-economy trade-offs integral to price reform must be made with reference to local political decision making processes...*

2.4 The application of welfare economics in water tariff setting

A consumer having a limited income at their disposal must make choices. Unlimited quantities of all desirable goods and services are not affordable. Demanding more of one thing will mean having less of another. Similarly society must make choices of how to use their scarce resources of labour, capital and natural resources (Johansson, 1991, pg 1). Welfare economics is concerned with how these decisions may benefit one group of society but not make another worse off. Ideally welfare economics must guide decision makers so that Pareto efficiency is attained in the economy, i.e. at which point it becomes impossible to improve the situation of some individual in society without making someone else worse off.

A social welfare function expresses a view on the distribution of welfare in society and is used to rank the possible states arising from decisions. An individual's welfare is measured by their consumer surplus, the area under the graph of a consumers demand curve for a commodity between the price they are willing to pay per unit and the market price they actually pay per unit (Johansson, 1991, pg 41) **(Figure 2.6)**

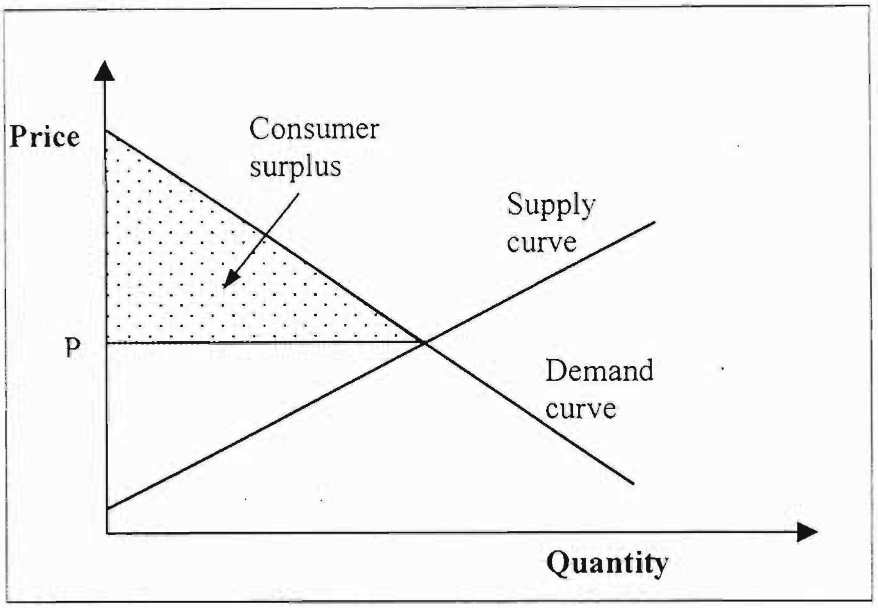

Figure 2.6: Consumer surplus shown by the area under the consumer demand curve above the price paid for all each unit of consumption. (Johansson, 1991, pg 41)

To measure social welfare we simply sum the individual consumer surpluses (Johansson, 1991, p48).

The consumer demand curve is generally referred to as a Marshallian market demand function and it reveals how much a consumer is willing to pay in addition to the present price. The Marshallian demand function is easily approximated using empirical observations of consumer behaviour (Bös, 1981 p5). The Hicksian compensating variation and equivalent variation methods of measuring consumer surplus were introduced as a more convenient way of expressing the change in welfare arising from a change in the price of a good. Unfortunately these measures are not observable in the market place (Johansson, 1991, p52). This study was confined to the Marshallian demand function, since the Marshallian surplus always lies between the two Hicksian surpluses and they are all only approximations of welfare (Bös, 1990, p7),.

Moilanen and Schulz (2002, p358) used the Marshallian consumer surplus to model how changes in policy approach will influence the optimal water tariff system. Their paper considers utilitarianism, weighted utilitarianism, and Rawlsianism social welfare functions to determine the best price discrimination rule for a low and high income consumer using a two step increasing block tariff structure.

2.5 Ramsey pricing

Frank P Ramsey (1903-1930) proposed a solution to the problem of raising a specific revenue by taxing different consumer products in such a way that it minimises the reduction in consumer utility (Ramsey 1927, pg 47). The taxes should be such that they reduce the consumption of each commodity by the same proportion. He showed that the tax on each commodity should be proportional to the sum of the reciprocals of each of the supply and demand elasticities (Ramsey, 1927, pg 56). In the case of an absolutely inelastic commodity all revenue can be raised through taxing it without reducing consumer utility, for example a tax on whisky. The unknown factor in applying the theory is the curvature of the supply and demand curves. The results will only be true for the applicable range of the estimated price elasticity (Ramsey, 1927, pg 60).

In the case of a water service provider the guiding principle of Ramsey pricing is to construct the tariff to maximize an aggregate of customers' benefits, subject to the constraint that the service providers revenues cover its total costs. Additional constraints are also included in some applications, including the constraint that no customer is worse off with Ramsey pricing than the uniform price schedule that provides the same net revenue for the firm. The net effect of Ramsey pricing is simply to reduce the percentage profit margin on each unit sold until the service provider's revenue equals its total cost (Wilson, 1999, pg 112).

The price for each unit includes an *ad valorum* or value-added tax to meet the service provider's revenue requirement. This tax is stated as a percentage mark-up inversely proportional to the price elasticity of the demand for that unit. Units with lower price elasticities are taxed more because their demands are curtailed less by the tax. In particular, the tax imposes a welfare loss due to the resulting departure from the fully efficient demands that would result from marginal cost pricing, and this welfare loss (as measured in terms of consumers' surplus) is roughly proportional to the price elasticity. The resulting pricing rule uses the firm's monopoly power efficiently to meet the revenue requirement (Wilson, 1999, pg 117).

Non-linear tariffs derived from the principles of Ramsey pricing suppose that the service provider is allowed to charge different prices for different increments. If marginal cost is constant then this is a kind of price discrimination created solely by the design of the tariff, since typically increments sold to one customer are generically the same, and the same as those sold to other customers. It is due to the utilities monopoly power that it is able to differentiate prices in an efficient way that allows it to meet its revenue requirement, with the restriction that the same tariff is offered to all customers (Wilson, 1999, pg 118).

Bös (1981, pg 56) provides a simple interpretation of Ramsey pricing, applicable to situations where cross price elasticity can be ignored because it is small in comparison with the direct elasticity. The Ramsey formula reduces to an *"inverse elasticity rule"*

$$\frac{\Delta P_1}{\Delta P_2} = \frac{\varepsilon_2}{\varepsilon_1}$$

Where:

$$\Delta P_i = \frac{P_i - C_i}{P_i}$$

P_i = price of i^{th} tariff block

C_i = marginal cost of i^{th} tariff block

ε_i = price elasticity of demand of i^{th} tariff block

In this case the ratio of the price-cost margin is equal to the reciprocal ratio of the price elasticities of demand.

3 Research methodology

This section of the dissertation presents the process followed in applying the Ramsey pricing principles to develop an alternative increasing block tariff. The problem statement is given in **Section 3.1.** The recent history of water supply and current water demand characteristics of consumers in Durban is presented in **Section 3.2**. This provides a context for the analysis that follows. **Section 3.3** deals with the sampling and data collection process. The statistical analysis of the data is presented in **Section 3.4** with the regression analysis being covered in **Section 3.5**. The output of the regression analysis is the estimated demand function and price elasticity of demand for low, middle and high income households. In **Section 3.6**, the marginal cost of domestic water supply is estimated. The application of Ramsey pricing and development of a new tariff structure is presented in **Section 3.7**. The methodology section concludes with a presentation of the welfare impact of the new tariff in **Section 3.8.**

3.1 Problem statement

The purpose of this dissertation was to investigate whether a tariff based on Ramsey pricing principles results in an increase in welfare for the domestic water consumers in Durban. The specific objectives of the research were:

- Establish the water demand characteristics of domestic households in Durban.
- Estimate the demand function and associated demand price elasticity of low, middle and high income households.
- Estimate the marginal cost of domestic water supply.
- Propose an increasing block tariff based on Ramsey pricing principles.
- Compare the impact on welfare of the proposed tariff against that of the current tariff by measuring the change in consumer surplus.
- Present the findings and make recommendations to the Durban city council regarding the application of Ramsey pricing principles in setting water tariffs.

The proposed tariff structure presented in **Figure 3.1** consisted of blocks that were targeted at specific income levels, low income, middle income and high income households. The increasing block tariff structure fulfilled the requirement of the government's free basic water policy and provided the first 6 kL per month free. A second block was priced to address the needs of poor consumers. The price of the third block and fourth blocks were set at a price which included a mark-up according to the end users ability to pay. The final block was set at a price that discouraged the wasteful or luxury consumption of water.

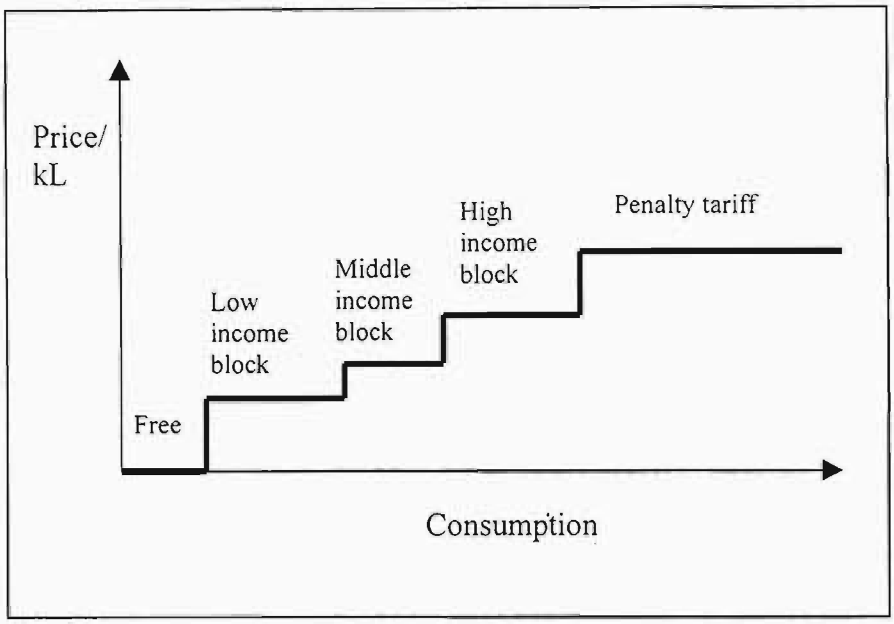

Figure 3.1: Structure of proposed increasing block tariff

The low income block is set at or just above the short run marginal cost of providing an additional kilolitre of water to a consumer. The price of each of the subsequent blocks is set according to the consumer groups willingness to pay. The penalty tariff is set at twice the calculated high income block tariff. One of the underlying purposes of this research is to determine an appropriate difference between the price of the tariff blocks that will maximise welfare distribution.

3.2 Recent history of water services in Durban

In 1992 the Durban City Council was restructured to form separate business units that would focus on the effective delivery of services. The Durban Water and Waste service unit was formed to provide water, waste water and solid waste services. The finances of the water department were ring fenced to ensure that revenue from water sales met the costs of providing water services. The water supply tariff was based on a two part tariff structure, a fixed charge and a consumptive charge. The same consumption charge was applied to both domestic and non-domestic consumers.

The Durban Metropolitan Municipality was formed in 1995. Durban Metro Water Services was created by amalgamating 43 separate water utilities and municipalities into one operational entity. The main purpose of the single body was to provide equal services to all citizens across the metro at the same tariff. The former black townships had received particularly poor water services in the past and cost recovery was negligible.

In 1996 the water losses in the former townships were between 60 and 80%. The pipe network was constructed in a mid-block layout making it particularly difficult to maintain, read meters, and police illegal connections. The billing database was also completely out of date. A large capital investment programme was started whereby new reticulation was laid in the road verges, meters installed and consumer details captured into the billing database. House to house visits were carried out informing and educating owners on the process of metering, bill payments and disconnections. By the end of 1998 most of the consumers in Umlazi and Kwa Mashu were being billed for water. It took another six months before these new consumers had adjusted their consumption to levels they could afford.

From 1993, water supply in the informal settlements was through a bailiff operated standpipe or prepaid ground tank system. The ground tank system consisted of a 200 litre tank at each dwelling which was filled once a day by a bailiff through a small reticulation network connected to the municipal water supply. By 1996 it was clear that the cost of collecting revenue from the prepaid tank system exceeded the cost of the water being supplied. A decision was taken to provide the tank system water supply at a zero tariff. The 200 litre tank effectively provided each household with 6 kL free water per month.

An increasing block tariff was first introduced for domestic consumers in 1996 with a penalty tariff for consumption exceeding 30 kL per month. A lower tariff was introduced in 1997 for consumption less than 6 kL per month. In 1998 this first block of 6 kL was provided free. This addressed the equity issue raised with free water only being made available to informal settlement households. Poor unemployed people did not only live in informal settlements, those poor people living in formal township houses also had the right to basic water services.

The development of the increasing block tariff and change in real prices between 1996 and 2003 is shown in **Figure 3.2**.

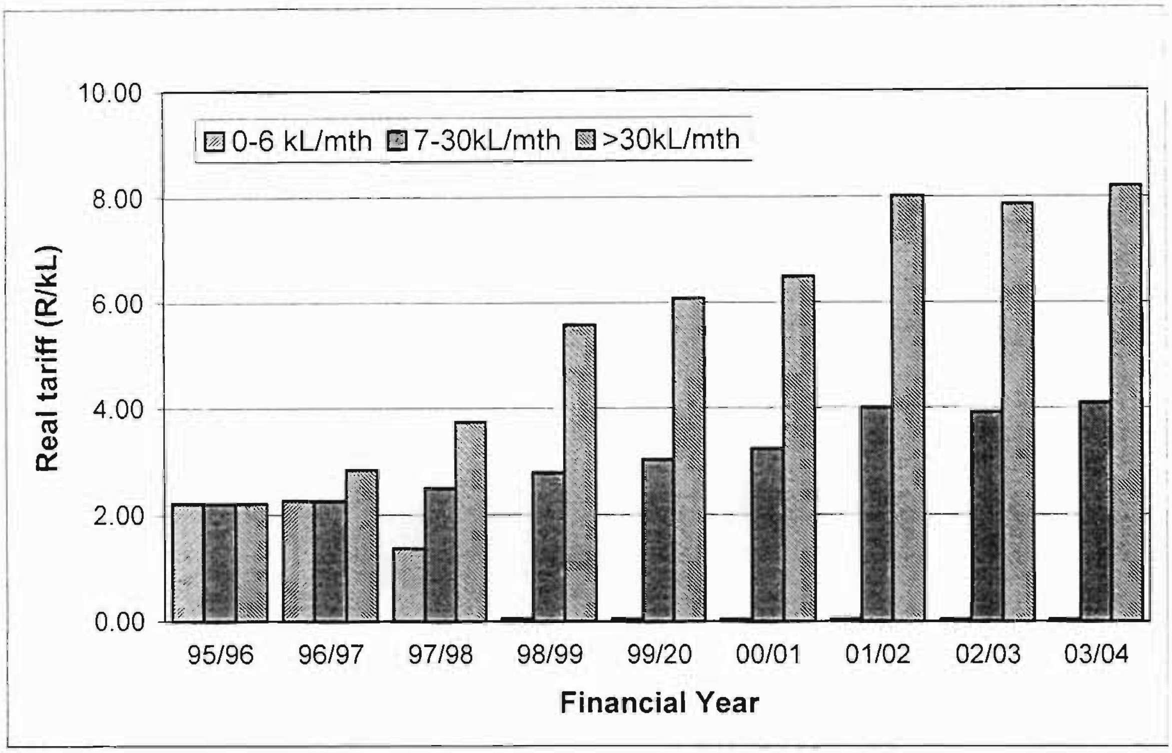

Figure 3.2: Change in real (base 2000) domestic water tariff between 1995 and 2003 showing the development of the increasing block tariff.

In 1997 the Umgeni Water Board notified the Durban Metro that it would need to construct a major catchment transfer scheme to ensure water resources for the future at the current growth rate in demand. This capital expenditure was to have a significant impact on the water tariff and was politically unacceptable and economically unsustainable. A demand management strategy was developed that would see water demand stay constant over the next 10 years. The stepped tariff, waste water recycling and water loss management systems put in place have actually dropped demand to 1994 levels. **Figure 3.3** shows the change in bulk water demand between 1988 and 2003 for the Durban and surrounding area now administered by the eThekwini Municipality. This reduction in demand was attained while at the same time new services were being supplied to previously unserved communities.

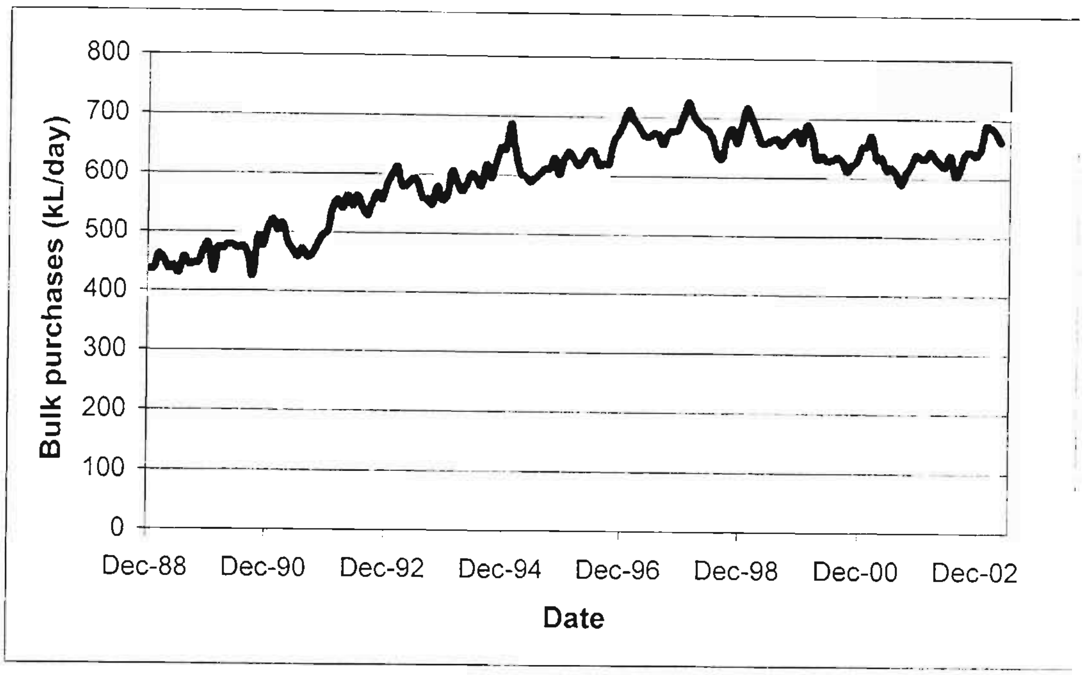

Figure 3.3: Water demand in Durban between 1988 and 2003 (Nicoll, 2003). (a water conservation strategy introduced in 1997)

During the run up to the 2000 local government elections, politicians placed a moratorium on disconnections in the former black townships. While certain politicians may have gained some support through this move, for many households it placed them in a debt trap. Without the threat of disconnections, these poor households spent their little money on other necessities. When the moratorium was lifted 12 months later, these poor households were faced with water bills they could not afford to pay. This led to a series of disconnections, meter tampering, connection removals and the installation of illegal connections. This resulted in an unprecedented loss of revenue and for the first time ever, the water department collected insufficient revenue to cover its costs. Political interference continues to hinder efforts to revive a culture of well-behaved consumers in the townships and the water arrears situation continues to deteriorate.

Finally, the water and waste services department is being restructured in 2003 under the eThekwini Municipality (formed in 2000), gaining efficiencies by finding synergies with other municipal departments and removing duplicated functions.

3.3 Characteristics of the eThekwini Municipality

The Greater Durban Metropolitan Area is administered by the eThekwini Municipality (www.durban.gov.za). According to the Census 2001 statistics, there are approximately 3.1 million people living within the eThekwini Municipality boundary (StatsSA, 2003b). There are approximately 60 000 households living in the rural areas, 150 000 households living in informal peri-urban settlements, and 560 000 families live in formal residential housing units (StatsSA, 2003b).

The municipality purchases treated potable water in bulk from the Umgeni Water Board (www.umgeni.co.za) and distributes it to all domestic and non domestic water users in its area of jurisdiction.

Details of the formal water consumers in Durban were obtained from the municipality's water account billing database. **Table 3.1** gives a breakdown of the consumer types and consumption in 2003.

Table 3.1: Summary of consumer types

Consumer type	Connections		Consumption	
	(No.)	(%)	(kL/d)	(%)
Domestic	336 939	95.5	327 487	52.3
Institutional	731	0.2	11 105	1.8
Commercial	12 655	3.6	209 129	33.4
Industrial	2477	0.7	78 533	12.5
Total	**352 802**	**100.0**	**626 256**	**100.0**

It is clear that domestic consumers form a significant proportion of the customer base. On the other hand non-domestic consumers only form 4.5% of the customers but account for 47% of sales.

Table 3.2 provides a breakdown of domestic consumer types and service level as at 7 April 2003. Consumer types are divided between single residential properties and cluster, or multiple dwelling properties. The consumer types are also differentiated between a normal unlimited supply and a limited supply (by means of a flow restricting device on the meter installation). Service levels are divided between normal full pressure connections and semi pressure or roof tank supply. Service levels are also differentiated between connections which are currently in service or disconnected.

Table 3.2: Breakdown of domestic consumer type and service level

	Single Residential		Multi Residential		
	Normal	Limited	Normal	Limited	**Total**
Full Pressure					**307 144**
In service	228 035	4 864	34 552	2	
Disconnected	37 216	1 083	1 388	4	
Semi Pressure					**29 795**
In service	24 441	197	1	0	
Disconnected	5 115	41	0	0	
Total	**294 807**	**6 185**	**35 941**	**6**	**336 939**

It is clear from **Table 3.2** that full pressure single residential connections made up the vast majority (80%) of domestic water connections. The research sample was drawn from this segment of the consumer database. Consumers who were disconnected in April 2003, or whose consumption was artificially limited by a flow restricting device were excluded from the sample as they were not well behaved consumers. An analysis of their consumption would not reflect their true willingness to pay for the water consumed.

3.4 Selection of low, middle and high income groups

The first step in finding a sample of low, middle and high-income consumers was to find a means of differentiating consumers according to income. As household income micro data were not available, the property value, as determined by the municipal property valuation roll, was used as a proxy for income. Although the municipal property valuation roll (of April 2003) did not represent the market value of each property, it did provide a consistent indication of the relative difference in income between households across the municipality.

The property valuation roll identified 291 900 properties as single residential units (this excluded cluster housing complexes, flats etc.) of which 300 had a value above R1.2 million. These 300 properties were excluded from the analysis since it was felt that it was unlikely, from the property description, that these properties were used as normal residences. At the lower end of the market all properties that had either a land value or building value of less than R1 000 were eliminated in order to exclude undeveloped properties. The lowest property value was then R3 500, which from the description appeared to be a valid residential property. The remaining 291 600 properties were then ordered according to property value and split into three equal proportions, representing the low income, middle income and high income households. The breakpoint for low income was all properties valued at less than R56 000. The breakpoint for high-income households was all properties above R154 400. All properties in between these two breakpoints were classed as middle income.

The property records were then joined with the billing records to flag individual consumer records as high, middle or low-income consumers. Unfortunately only 70% of consumer records could be joined to the valuation role database. This was because 30% of the billing records had been captured on a separate database which did not have a field to link it to the property valuation database. It was however still possible to obtain representative samples of each income group from the joined records.

3.5 Identifying well behaved consumers

It was only possible to determine a consumer's price elasticity of water demand if they were actually paying for the water they were consuming. Households who had fallen behind with bill payments, or stopped paying, were obviously using more water than they wished to pay for. Including these consumers in the analysis would have given skewed results regarding their change in consumption with changes in price. It was necessary to only select well-behaved consumers. This was done by eliminating all consumers whose arrears (in April 2003) exceeded the cost of three months of their average consumption. This did not exclude consumers who had at some stage, during the analysis period, fallen behind with payments. The assumption was made that these consumers were still managing their demand despite financial difficulties, and had rehabilitated themselves as soon as financially possible. Previous research on low income household water payment strategies had found that consumers still tried to manage their demand despite being slightly in arrears. It was only when their arrears rose to a level that they could not afford to settle in the long run that they grew despondent and stopped managing their demand (van Vuuren, 2003, pg 92).

3.6 *Cleaning the data*

It was necessary to ensure that the samples selected for each income group did not consist of corrupt data. While every effort had been made by the billing department to ensure the integrity of its data it was not possible to eliminate all data capture errors. One example of a data capture error would be where a non-domestic consumer was incorrectly classified as domestic. This problem was eliminated by only selecting billing records where the consumer was classified as *domestic* in the water billing system and as *residential* in the town planning system.

A potentially more serious error was the incorrect capture of meter readings in the billing system database. It was generally accepted that the billing verification process eliminated these errors by flagging readings that fell outside an acceptable variation of the average reading and resulted in the meter reading being checked. According to the billing records some monthly meter readings were estimated. This generally happened over the December holiday period, but could also have happened for a number of other reasons, including the meter reader not being able to find the meter box, due for example, it being covered by a pile of building material. This meant that the reading for that month was estimated based on the average consumption over the previous 12 months. From a statistical point of view this would not have changed the sample statistics significantly, however it was decided to eliminate consumer records where more than two readings had been estimated during any 12 month period.

Another concern with meter readings was where a consumer had experienced a burst or serious leak in their internal plumbing. The meter reading would have reflected high consumption, however this consumption did not represent what the consumer was willing to pay for water, thus defeating the objective of the analysis. This situation was handled by looking at records where the peak consumption in any particular month exceeds three times the average consumption for the year. These consumers were then excluded from the analysis.

A difficult situation to deal with was the incidence of *shack farming*, especially in the former black townships,. A domestic consumer in a residential area could rent out back yard shacks to poor households. The water consumption of all the households was then reflected on the meter reading of the single residential property. This problem was ignored in the analysis.

Shack farming was a phenomenon created by the apartheid system by restricting black people from living outside of defined *black* townships. With the repeal of these laws, many households moved out of backyard shacks and into informal settlements closer to work opportunities in the city.

The final check was to plot the monthly average, variance and standard variation of each consumer group. Any significant deviation from the average was then investigated to isolate the records generating the anomaly. In one such plot of the average monthly consumption for each consumer group we found that the consumption of the low-income households exceeded that of the middle-income households at the end of 1998. At first this could not be explained. The sample variance and standard deviation plots for the same period clearly showed some form of an anomaly present during the last three months of the year. A plot of the number of consumer accounts in the sample also showed a sudden increase during the same period for low-income households. Looking at individual records it became clear that the great majority were from the former black townships of Umlazi and Kwa Mashu and Ntuzuma.

Before 1998 consumers in these areas were charged a flat rate for water irrespective of their consumption. During 1997 and 1998 meters were installed and the consumers were registered in the billing database. The billing data showed that these consumers were using a lot more water when the meters were first read. These same households adjusted their water demand over the next six months so that it fell in line with what other low-income consumers were using and paying for. This clearly demonstrated the impact of billing on water demand and deserves further study. However it distorted the data since the consumers were obviously using more water than they were willing to pay for. The impact on the data was corrected by ignoring these new consumers billing records for the first six months that they were connected. This gave them time to adjust their household water demand to an amount they could afford.

The outcome of this cleaning exercise was a set of consumer records that truly reflected individual households willingness to pay for water services. This was then the clean population from which the sample was drawn

3.7 *Statistical analysis of the billing data*

A cross section of 5 000 consumers was selected from each income group from the clean population (in April 2003). The monthly billing records for each consumer in the sample were then extracted from the billing system archives. At least 1 263 records were required for each consumer group in order to estimate the average consumption for the month with the 99% confidence required (Appendix A1).

Many consumers, especially in the lower income groups had only been captured onto the billing system since 1988. This meant that for the low income consumers, the sample had less than 1000 consumers prior to June 1988. However the estimated mean consumption even for this smaller sample size was still within 1.2 kL per month of the true mean (at a 99% confidence level).

The sample of billing records was processed to determine the mean, median, variance and standard deviation of monthly and annual consumption of the three income groups. A 99% confidence interval was calculated for each estimate of average monthly consumption. A summary report of the average monthly water consumption of each of the income groups during each financial year (July to June) is given in **Table 3.3**. The full results of the statistical analysis are given in Appendix A2.

Table 3.3: Average monthly water demand of low, middle, high and all income groups

	Low Income		Middle Income		High Income		All Income	
Financial Year	**Mean (kL/mth)**	**Median (kL/mth)**	**Mean (kL/mth)**	**Median (kL/mth)**	**Mean (kL/mth)**	**Median (kL/mth)**	**Mean (kL/mth)**	**Median (kL/mth)**
1996/1997	20.9	18.3	23.8	21.0	34.7	29.1	28.4	23.7
1997/1998	20.4	18.0	23.2	20.4	34.1	28.8	28.0	23.4
1998/1999	19.2	16.5	23.2	20.7	34.9	30.0	27.3	22.8
1999/2000	18.3	15.3	22.9	20.7	34.5	30.0	25.1	21.0
2000/2001	16.5	14.1	22.4	20.4	33.9	29.4	24.1	20.4
2001/2002	15.7	13.5	21.7	19.8	32.8	28.2	23.3	19.8
2002/2003	15.2	12.9	21.6	19.8	32.6	28.2	22.9	19.5

The confidence interval for the annual mean demand is generally better than 0.5 kL/month. For the monthly mean demand this confidence interval is generally better than 1 kL/month.

Figure 3.4 shows a plot of how average household water demand had changed during the study period. Higher income groups used more water than lower income groups. There had been a general downward trend in water consumption over the period for all income groups. The lower income groups had reduced their demand more than the higher income groups. The trend of low income households was also less variable than middle or high income groups.

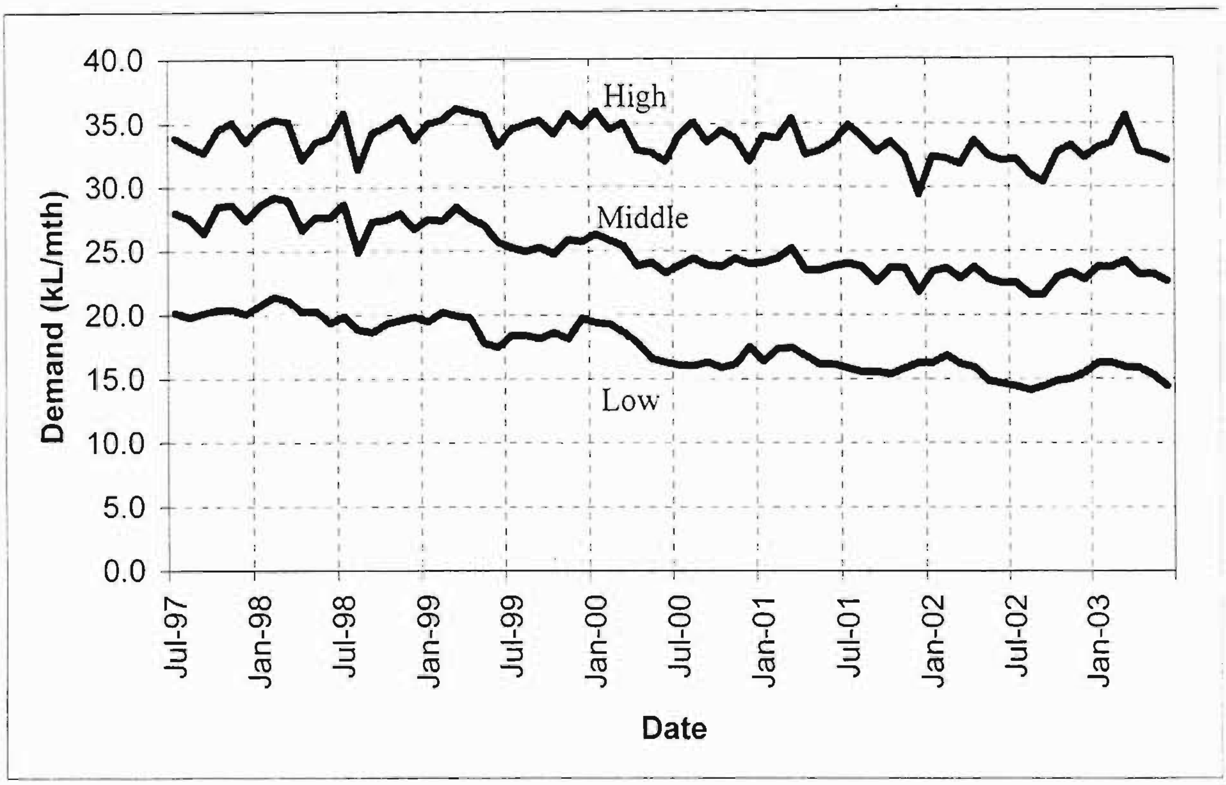

Figure 3.4: Graph indicating the change in monthly average household water consumption between 1997 and 2003 for low, middle and high income group samples (n ≈ 4000 records per group per month)

A frequency distribution of the annual mean monthly demand was generated from the sample data. The full results are presented in Appendix B. It is interesting to note the differences in frequency distribution between the three different income groups in 2002/2003 (**Figure 3.5**). The distribution for low income consumers is highly skewed to the left, while the distribution of high income consumers is more symmetrical. Taken together, the frequency distribution and summary of mean and median demands allows the following observations. The modal demand of low income households was about 9 kL per month, and 50% used less than 13 kL, whilst the average demand was 15 kL per month. The median and average consumption of middle income households was 19 and 22 kL per month respectively. High income households used 33 kL per month on average, and 50% used more than 28 kL per month. These observations are important for making decisions on the appropriate size of the pro-poor and other tariff blocks.

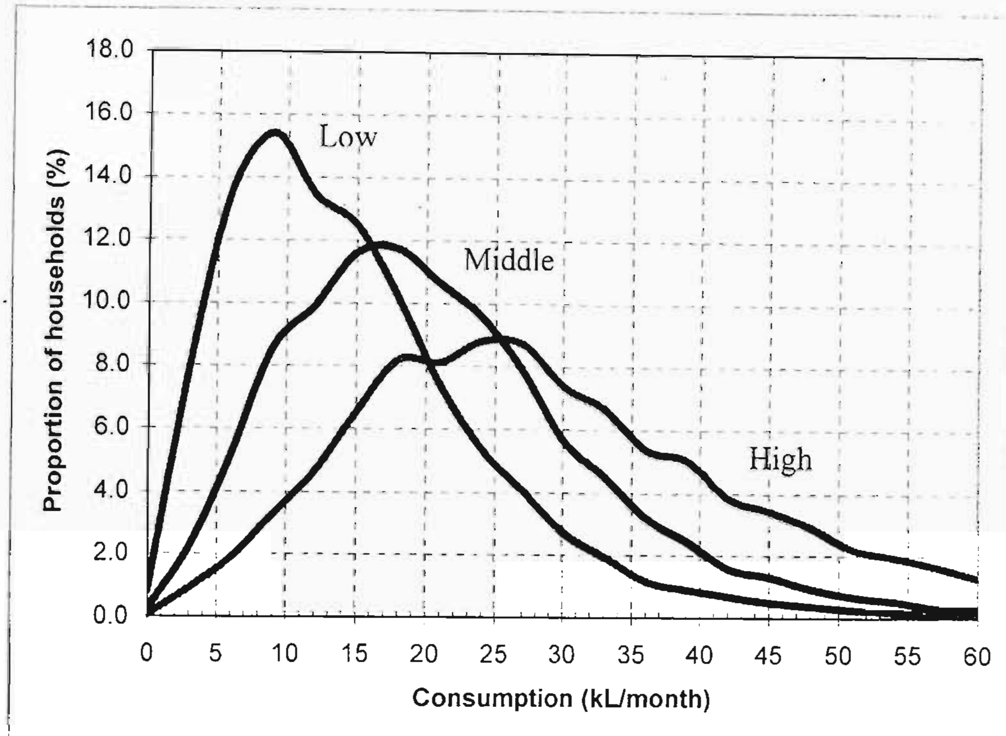

Figure 3.5: Frequency distribution of water consumption for low, middle and high income groups in 2002/2003 (n ≈ 12 000).

3.8 Regression analysis

Regression analysis investigates the impact that various factors may have on household water demand. Billings and Jones (1996, pg 4) suggested that population, economic cycles, technology, weather and climate, price and conservation programmes may all have a significant impact on water demand over time. These factors were each considered and treated as follows:

- Population: This research was concerned with the change in water demand in an average household over time. According to the national census, between 1996 and 2001, the average household size in eThekwini dropped from 4.10 to 4.00 (StatsSA, 2003a, StatsSA, 2003b). This may have been due to the impact of HIV/AIDS, but is much more likely to be due to the delivery of low cost housing. For the purpose of this research it was not practical to determine the change of household size for each property in the sample. It was assumed that the average household size of the sample had remained constant overall and that any reduction in one household was offset by additions in another.

- Economic cycles affect commercial and industrial water demand more than domestic demand. There is however an impact on the household in terms of the income available to spend on water as apposed to other goods. It was assumed that by adjusting the nominal tariff by the Consumer Price Index (StatsSA, 2003c), it was possible to simulate the impact of economic cycles on the average household in that real tariff growth resulted in a reduction in spending on other goods and services unless water consumption is reduced.
- Water efficient technologies do have an impact on water demand as households replace inefficient appliances over time. Investments in efficient technology was not considered to be a factor in determining water demand but rather a result of pressure from increasing water price and conservation programmes.
- Weather and climate: A clear seasonal trend in average water household consumption was observed in **Figure 3.4**. Monthly rainfall and temperature data, available from the South African Weather Services for Durban, were used in the regression analysis to explain changes in water demand (Swart, 2003).
- Price: One of the primary objectives of the regression analysis was to determine the impact that changes in the water tariff over time had on water demand. The actual tariffs were adjusted by the consumer price index to give a real price based on year 2000 value
- Water conservation programmes: No new or changed water restrictions had been applied during the study period. Households who had fallen into arrears were encouraged by the water department to attend water conservation education programmes to assist them in managing their water demand. All households who were more than three months in arrears were excluded from the sample as they did not represent well behaved consumers.

3.8.1. Developing the regression model

The first step in developing the regression model was to plot the data in order to detect relationships which could be explained with a mathematical function. Water consumption was plotted against real price, temperature and rainfall. These relationships are shown in **Figures 3.5, 3.6** and **3.7** respectively.

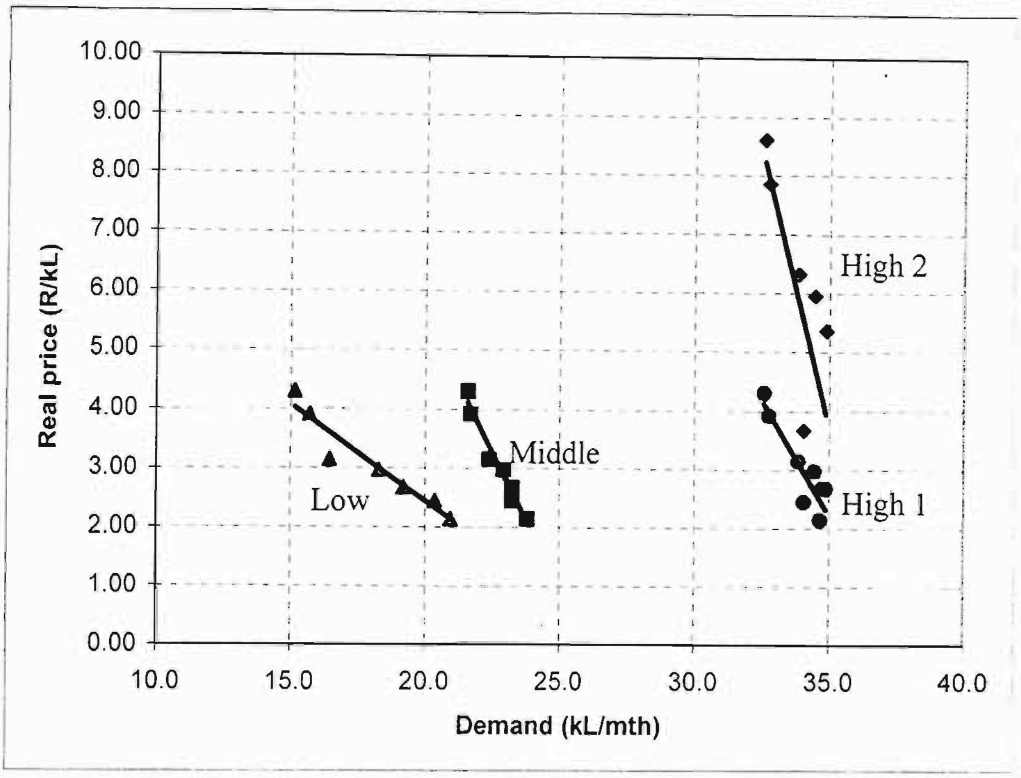

Figure 3.6: Relationship between average monthly demand and real marginal price (base 2000) for low, middle and high income groups.

In **Figure 3.6** the average monthly demand over a financial year (July to June) has been plotted against the corresponding real tariff for the period. The average demand for middle and low income groups has been plotted against the real tariff for the 6 to 30 kL block while the average demand for high income groups has been plotted against the real tariff for both the 6 to 30 kL/mth block (High 1) and the greater than 30 kL/mth block (High 2). The mean consumption for high income households falls above the 30kL/mth mark but the median consumption falls below 30kL/mth. It was not clear which price high income households were responding to. A clear relationship between increasing price (or tariff) and decreasing household water demand or consumption was observed for all income groups. This relationship was more significant in lower income levels in comparison with higher income levels. This relationship could be described by a linear function but would probably be better described by a logarithmic function.

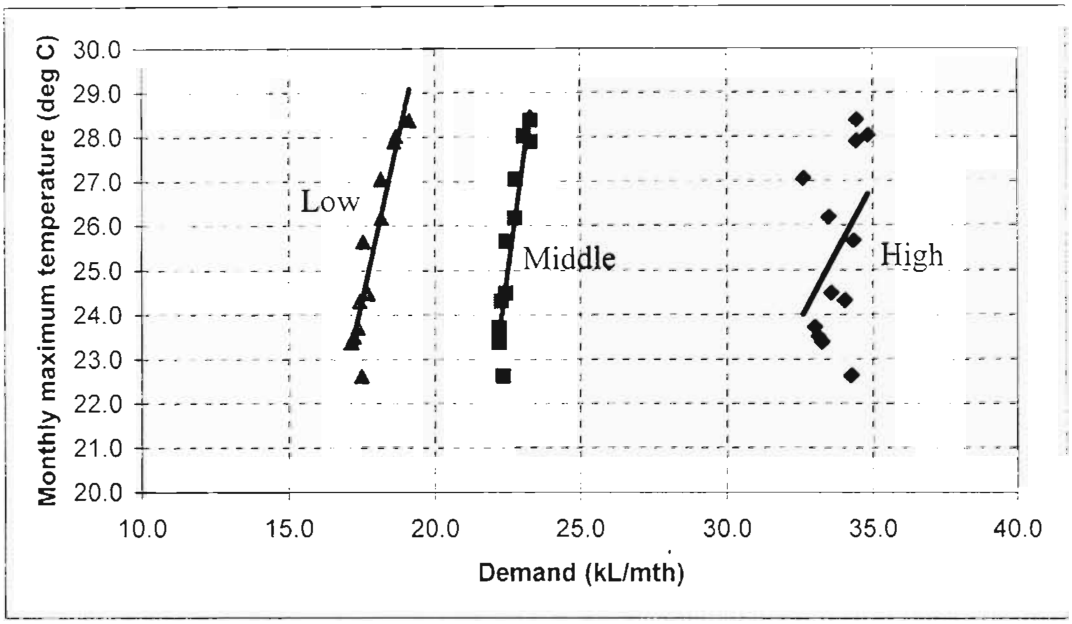

Figure 3.7: Relationship between average monthly water demand and average monthly maximum temperature for January to December (1996 to 2003) for low, middle and high income groups.

In **Figure 3.7** the average monthly maximum temperature has been plotted against the average demand for the corresponding month between 1996 and 2003. There appears to be a relationship between increasing temperature and increasing water demand. This relationship was more positive for lower income groups than higher income groups. The relationship was far more variable for the high income group in comparison with middle and low income households. A linear or increasing logarithmic function could be used to describe the relationship.

In **Figure 3.8**, the average monthly rainfall between 1996 and 2003 was plotted against the average monthly water consumption during the same period. There appeared to be a similar relationship between rainfall and demand as was seen between temperature and demand. It was expected that demand would decrease as rainfall increases. The observed relationship was probably due to a high correlation between rainfall and temperature. The regression analysis would test the significance of these explanatory variables and if necessary, rainfall would be dropped as it appeared to be far more variable than temperature in its relationship with demand. As with temperature, both linear or logarithmic functions could be used to describe the relationship.

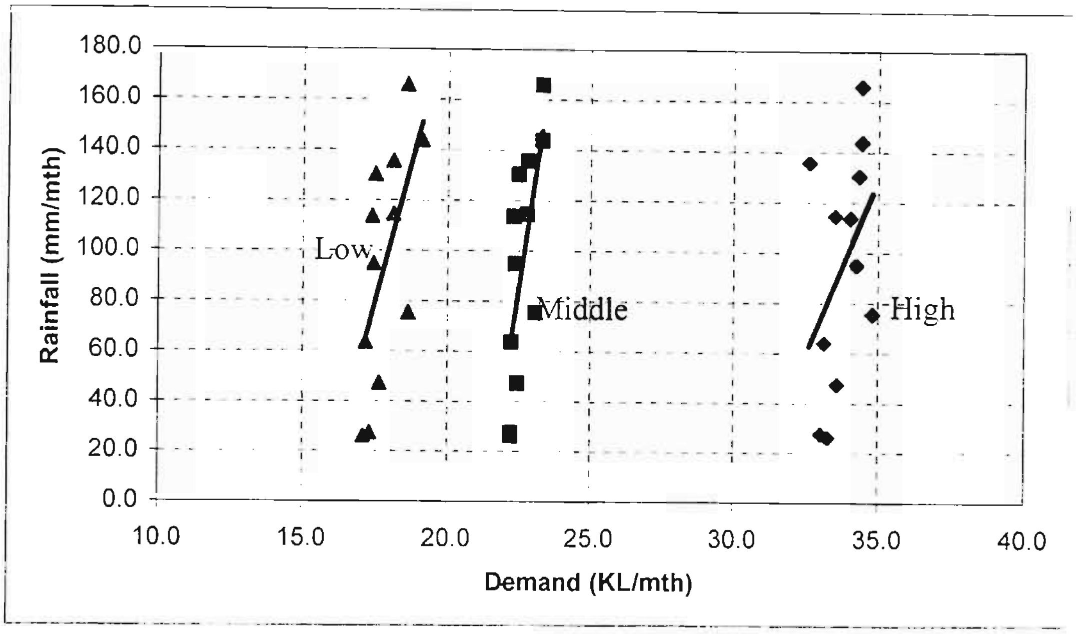

Figure 3.8: Relationship between average monthly demand and average monthly rainfall for January to December (1996 to 2003) for low, middle and high income groups.

A regression model was proposed based on the observations of the relationships between water demand and price, temperature and rainfall. Both a linear and a logarithmic function were proposed to test the relationship between demand and the three explanatory variables. The linear function found the sum of the impact of the three variables while the logarithmic function found the product of the three explanatory variables. The best function would then be selected based on the results of the regression analysis.

$$Q = B + B_1 \times \text{Price} + B_2 \times \text{Temp} + B_3 \times \text{Rain} \quad (3\text{-}1)$$

$$Q = C \times \text{Price}^{C_1} \times \text{Temp}^{C_2} \times \text{Rain}^{C_3} \quad (3\text{-}2)$$

Where

Q = monthly household water consumption (kL/mth)

B and C = constant or intercept of models

B_1, B_2, B_3 and C_1, C_2, C_3 are the slope coefficients of their respective explanatory variables.

Taking the natural logarithms of each side of (3-2) yielded:

$$\ln(Q) = \ln(C) + C_1\ln(\text{Price}) + C_2\ln(\text{Temp}) + C_3\ln(\text{Rain}) \quad (3\text{-}3)$$

The demand function represented by both Equations (3-1) and (3-3) are linear and the coefficients could be estimated using ordinary linear regression methods. An attractive feature of the model given in Equation (3-3) was that the slope coefficient C_1 measured the elasticity of demand in respect to price, that is the percentage change in demand for a given percentage change in price. Using Equation (3-1) the arc elasticity would need to be calculated over the range of price and demand.

3.8.2. Analysing the regression model

The average monthly water consumption for each of the income groups was regressed against the real marginal tariff (base 2000 price), average monthly maximum temperature and average monthly rainfall for the corresponding metering period between July 1996 and June 2003 (84 months). The full table of data used in the regression analysis is presented in Appendix C. **Table 3.4** summarises the most important statistics of each regression.

The initial runs for both the linear and log linear models consisted of marginal price, temperature and rainfall data for each income group. The results of these regressions were analysed to see if any variables were insignificant. The critical value for a 95% confidence level and 83 degrees of freedom was that any variable with an absolute t statistic of less than 2.04 should be dropped from the model. It was found that in the models of the high and middle income groups, the impact of the rainfall variable was insignificant. In the low income models the rainfall variable was marginally significant. Similarly the t statistic for temperature showed that while it remained significant for middle and low income models, it was only marginally significant in the high income model. These findings led to further models being developed which only included temperature and price, or price on its own. Price was significant in all the models produced, being most significant in lower income models.

The significance of the regression models as a whole was checked by ensuring that the F statistic was greater than the critical F value for a 95% level of confidence. In all cases it was found that the regression model is significantly better in explaining water demand than would be achieved by just using the mean demand value found for the analysis period.

Table 3.4: Summary of regression model statistics

Model	Form	Variables	Adjusted R square	Standard error	F statistic
High income	Log-linear	Price >30kL/mth, temp and rain	0.176	0.042	6.9
	Log-linear	Price 6-30kL/mth, temp and rain	0.254	0.040	10.5
	Linear	Price >30kL/mth, temp and rain	0.216	1.363	8.6
	Linear	Price 6-30kL/mth, temp and rain	0.267	1.318	11.1
	Log-linear	Price >30kL/mth and temp	0.184	0.041	10.4
	Log-linear	Price 6-30kL/mth and temp	0.262	0.039	15.7
	Linear	Price >30kL/mth and temp	0.225	1.355	13.0
	Linear	Price 6-30kL/mth and temp	0.275	1.31	16.7
	Log-linear	Price >30kL/mth	0.139	0.042	14.4
	Log-linear	Price 6-30kL/mth	0.215	0.041	23.8
	Linear	Price >30kL/mth	0.177	1.397	18.8
	Linear	Price 6-30kL/mth	0.229	1.352	25.6
Middle income	Log-linear	Price 6-30kL/mth, temp and rain	0.743	0.009	81.2
	Linear	Price 6-30kL/mth, temp and rain	0.747	0.460	82.7
	Log-linear	Price 6-30kL/mth and temp	0.745	0.020	122.8
	Linear	Price 6-30kL/mth and temp	0.750	0.457	125.2

Model	Form	Variables	Adjusted R square	Standard error	F statistic
	Log-linear	Price 6-30kL/mth	0.546	0.027	100.9
	Lin	Price 6-30kL/mth	0.558	0.608	105.6
Low income	Log-linear	Price 6-30kL/mth, temp and rain	0.869	0.050	184.4
	Linear	Price 6-30kL/mth, temp and rain	0.811	1.114	119.4
	Log-linear	Price 6-30kL/mth and temp	0.858	0.052	252.2
	Linear	Price 6-30kL/mth and temp	0.784	1.188	151.9
	Log-linear	Price 6-30kL/mth	0.829	0.057	404.2
	Linear	Price 6-30kL/mth	0.765	1.240	271.4

The final test of significance was with the adjusted R^2 values. The models with the highest R^2 value were the most significant. In the case of the high income households the linear model that incorporated both marginal price (6-30kL/mth) and temperature was most significant, explaining 28% of the variability in water demand. The log-linear model with the same variable gave very similar results. Price (6-30kL/mth) on its own explained 23% of the variability using the linear model or 22% using the log-linear model. The models using the >30kL/mth tariff as one of the explanatory variables could not explain more than 23% of the variability in demand. This is probably due to the fact that the median consumption of the high income group was less than 30 kL a month. The low explanatory power of the models for high income households may not have been very satisfactory, but was not unexpected considering the weak relationships observed in the graphs between water demand and the explanatory variables.

The models for middle income households using price and temperature was able to explain 75% of the variability in water demand with the explanatory power of the linear model being slightly better than the log-linear model. Price on its own accounted for 56% of variability in demand. Finally the log-linear models for low income households using price, temperature and rainfall successfully predicted 87% of the changes in demand. Once again the impact of price was significant, accounting for 83% of the variability in demand.

The most significant demand functions for both the linear and log linear regression models are presented in **Table 3.5**.

Table 3.5: Estimated linear and log-linear demand functions for low, middle and high income groups (price based on year 2000 value).

Income group	Form	Demand function
Low	linear	$Q = 23.75 - 3.07 \times Price + 0.13 \times Temp + 0.006 \times Rain$
	log-linear	$Q = e^{2.69} \times Price^{-0.55} \times Temp^{0.24} \times Rain^{0.01}$
Middle	linear	$Q = 20.98 - 1.02 \times Price + 0.19 \times Temp$
	log-linear	$Q = e^{2.57} \times Price^{-0.14} \times Temp^{0.22}$
High	linear	$Q = 32.92 - 1.10 \times Price \div 0.17 \times Temp$
	log-linear	$Q = e^{3.22} \times Price^{-0.10} \times Temp^{0.13}$

Note that it is possible to estimate demand in terms of price only by substituting the average annual monthly maximum temperature (25.5 °C) and the average annual monthly rainfall (91.5 mm) into the above functions.

3.9 *Price elasticity of water demand*

The price coefficient found in the log linear regression model gave a direct estimate of the price elasticity of water demand. The price elasticity of demand could also be calculated with the linear regression model by multiplying the price coefficient by the average real price divided by the average demand The estimates of price elasticity found using the most significant regression models are summarised in **Table 3.6** together with the applicable 95% confidence interval.

Table 3.6: Estimated real price elasticity of water demand for low, middle and high income groups.

Income Group	Form	Price elasticity of demand	95% lower bound	95% upper bound
Low	Log-linear	-0.55	-0.50	-0.60
	Linear	-0.52	-0.46	-0.58
Middle	Log-linear	-0.14	-0.12	-0.16
	Linear	-0.14	-0.12	-0.16
High	Log-linear	-0.10	-0.06	-0.14
	Linear	-0.10	-0.06	-0.14

There was no difference in the value of the price elasticity of demand between the linear or log-linear models for the middle and high income groups. For the low income group there was a slight difference. The price elasticity found using the log-linear model was assumed to be better estimate since the log-linear model performed marginally better than the linear model in the regression analysis.

3.10 Marginal cost of water

An important input into the Ramsey pricing formula was the marginal cost of the service. Determining the marginal cost of the water service is a subject of debate on its own. For the purposes of demonstrating the application of Ramsey pricing, it was assumed that the short run variable cost of providing water services in Durban was an acceptable approximation of the marginal cost of water. The annual financial statements of the ring-fenced water services department were used to determine the variable cost. The main cost components of water services during the previous 3 financial years are provided in **Table 3.7** (eThekwini Municipality, 2002, pg 293-295, eThekwini Municipality, 2001, pg 294-299). The costs were roughly assigned to annual fixed cost per consumer, annual fixed cost per kL, and annual variable cost per kL. The fixed cost per consumer accounted for the cost of metering, billing, and customer services. The fixed cost per kL accounted for planning, construction and maintenance of water supply infrastructure, and the variable cost per kL accounted for the cost of purchasing and distributing treated water to consumers.

Table 3.7: Annual fixed and variable cost components of eThekwini Water Services between 1999 and 2002.

Description	2001/2002 (R'000)	2000/2001 (R'000)	1999/2000 (R'000)	Ave % of Total (%)
Per consumer				
Fixed Costs				
Salaries and Wages	110 479	103 654	78 721	12
General expenses	159 581	155 682	177 135	19
Contributions*	23 477	21 917	17 760	2
Recoveries**	-96 156	-112 605	-132 687	-13
Total	**197 380**	**168 648**	**140 929**	**20**
Per kL supplied				
Fixed costs				
Capital Charges	153 505	141 361	122 201	16
Repairs and Maintenance	43 651	48 374	43 232	5
Sub Total	197 156	189 734	165 433	22
Variable costs				
Water Purchases	549 915	470 370	432 411	57
Chemicals and Electricity	7 488	6 068	6 660	1
Sub Total	557 402	476 438	439 072	58
Total	**754 558**	**666 172**	**604 505**	**80**
Grand Total	**951 939**	**834 820**	**745 434**	**100**

Note* Contributions reflect the cost of finance and human resources support provided by other council departments.

Note** Recoveries reflect the cost of plant, labour and materials accounted for under salaries and wages and general expenses which were also charged against capital projects and the repair and maintenance of infrastructure.

If the water service provider was to charge consumers according to the actual cost incurred in serving the consumer then it is clear from **Table 3.7** that 20% of total cost must be distributed evenly among all consumers as a fixed charge, 22% should be a fixed charge assigned to consumers pro rata to their average demand as the cost of providing the infrastructure necessary to meet this demand, and the remaining 58% of costs must be recovered through a consumption tariff. **Table 3.8** illustrates such a tariff structure using data from **Table 3.7** for the 2001/2002 financial year.

Table 3.8: Calculation of fixed and variable costs associated with full cost recovery for the 2001/2002 financial year.

Description	2001/2002
Total fixed costs (R'000)	197,380
Total fixed cost (R'000)	197,156
Total variable costs (R'000)	557,402
Connections (No.)	352,802
Purchases (kL'000)	261,185
Sales (kL'000)	182,358
Fixed cost per consumer connection (R/mth)	46.62
Fixed cost per kL demand (R/mth)	1.08
Variable cost per kL Purchases (R/kL)	2.13
Variable cost per kL Sales (R/kL)	3.06

Notice that in **Table 3.8** the variable costs have been calculated using both the quantity purchased (i.e. the quantity purchased from Umgeni Water) and sold (i.e. the quantity sold to consumers). The difference between the two is the cost of non-revenue water. This non-revenue water (30% of purchases) is a cost incurred by the service provider due to background losses (approximately 10% of water in pipes is lost through leaks which cannot be economically repaired) and inefficiencies in reducing water loss by repairing major leaks, eliminating illegal connections, and maintaining metering systems.

The short run marginal cost of supply would be approximately equal to the variable costs of supplying an additional kL of water. From **Table 3.7** the variable cost was made up of bulk water purchases (99%) and chemicals and electricity (1%) It is clear that the bulk water tariff for water purchased from the Umgeni Water Board is a fair approximation of the short run marginal cost of water supply in Durban.

In the long run all costs can be considered to be variable. Fixed costs will vary according to the number of consumers in the system and the additional infrastructure required for water distribution. The cost per consumer and the cost per kL of water distributed will remain fairly constant in real terms during the long term. For the purposes of setting tariffs, the cost per customer and the cost per kL of water distribution infrastructure could still be considered to be a fixed cost in the long run. Increasing variable costs will be mainly a function of the increasing diseconomies of scale associated with tapping water resources further away from the point of use. These costs will be reflected in the bulk water charges from Umgeni Water.

In 2002 the Umgeni Water Board changed its tariff methodology to ensure a constant tariff in real terms over the long term. The tariff model was based on the long term cash flows required to meet the demand for additional water resource development, rather than balancing levels of expenditure during any one financial year. The organisations debt level would increase during the initial period and then decrease as net cash flows become positive (Umgeni Water, 2002, pg 29). It was therefore assumed that for Durban, the bulk water tariff was a good approximation of their long term marginal cost.

3.11 Application of Ramsey pricing

The purpose of this dissertation was to apply the Ramsey Pricing formula to determine a pro-poor tariff structure for Durban. The inputs required were the marginal cost of supply and the price elasticities of demand for each of the consumer groups. In order to calculate and propose a tariff it was also necessary to establish appropriate block sizes and state a revenue requirement.

3.11.1. Setting the block size

Setting the block size has traditionally been the function of the political authorities. The policy was to ensure that the poor have access to affordable water services while the rich pay a premium to cross subsidise the consumption of low income groups. In practice the size of the pro-poor block has often been set too large, covering all low income demands as well as most of the high income demands. The water service provider has then found it difficult to raise sufficient revenue without setting a relatively high tariff for this pro-poor block.

In order to guide decision makers in their deliberations this research has considered the following three options:

- **Old tariff**: The existing tariff structure for 2002/2003 was used with the first block of 6 kL/month supplied free of charge. The second block extended to 30 kL/month. The penalty block started from 30 kL/month. A fixed charge was levied at 6 kL/month and at 12 kL/month
- **New tariff 1**: The first block was set at 6 kL/month. The limit of the pro-poor block was set at a quantity that ensures that it accommodates the demand of at least 50% of

the low income household group. The step from pro-poor block to the next block was set 12 kL/month, approximately equal to the median demand of low income households in 2002/2003. The steps in subsequent blocks were also set approximately equal to the median demand of the middle and high income household groups; at 18 and 27 kL/month respectfully. The penalty block started at 27 kL/month. Fixed charges were levied at 6 kL, 12 kL and 18 kL per month.

- **New tariff 2**: The first block was set at 6 kL/month. The end of the pro-poor block was set at 15 kL/month, approximately equal to the average demand of low income households. The next step for the middle income group was set at 21 kL/month. The step for high income households was set at 30 kL per month rather than the average demand of 33 kL/month. This was to preserve the demand management impact of the existing penalty tariff starting at 30 kL/month. Fixed charges were levied at 6 kL, 15 kL and 21 kL per month.

The accumulated frequency distribution shown in **Figure 3.9** guided the setting of these blocks and shows the spill over of other income groups using water in the targeted block.

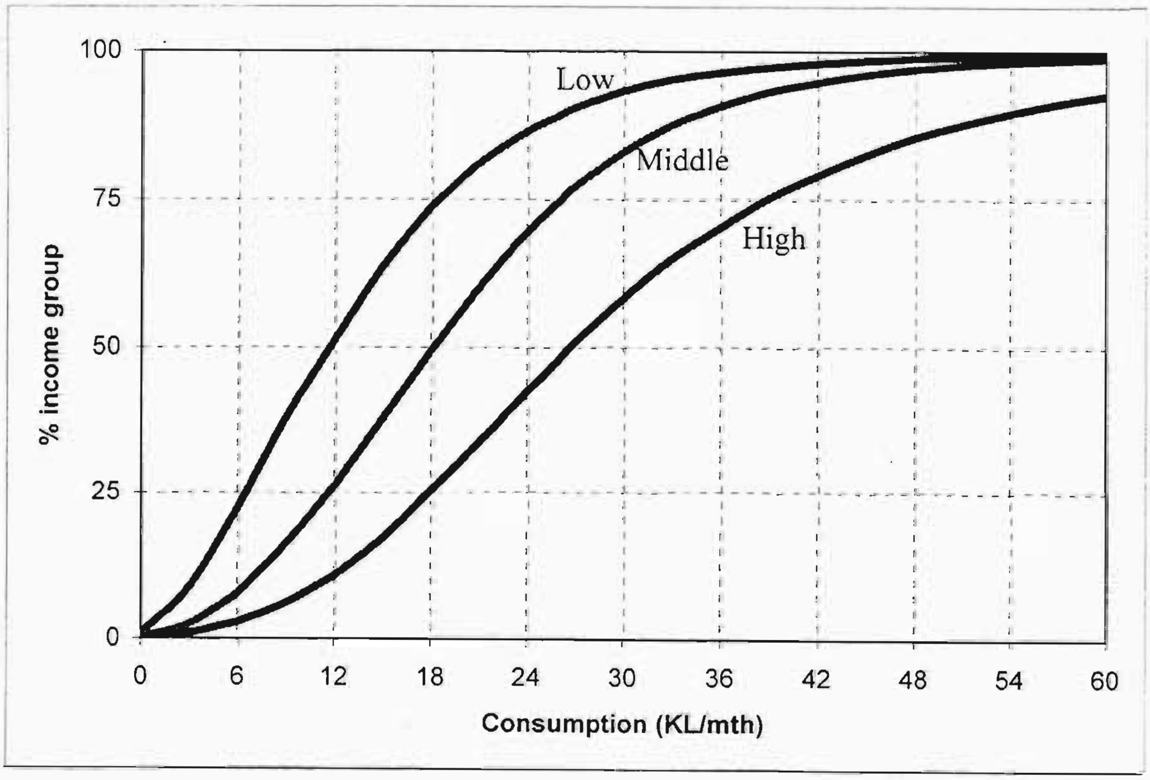

Figure 3.9: The accumulated frequency distribution of the low, middle and high income groups in 2002/2003.

Table 3.9: Proposed block structures showing the proportion and accumulated proportion of consumers from the low, middle and high income households in each block

Tariff (kL/mth)	Proportion consumers (%)				Accumulated proportion consumer (%)			
	Low	Middle	High	Total	Low	Middle	High	Total
OLD TARIFF								
0> ≤6	22	8	3	**11**	22	8	3	**11**
6> ≤12	29	19	8	**18**	51	26	11	**29**
12> ≤30	42	57	48	**49**	94	83	59	**78**
>30	6	17	41	**22**	100	100	100	**100**
NEW TARIFF 1								
0> ≤6	22	8	3	**11**	22	8	3	**11**
6> ≤12	29	19	8	**18**	**51**	26	11	**29**
12> ≤18	23	23	15	**20**	74	**50**	26	**50**
18> ≤27	17	28	26	**24**	91	78	**51**	**73**
>27	9	23	49	**27**	100	100	100	**100**
NEW TARIFF 2								
0> ≤6	22	8	3	**11**	22	8	3	**11**
6> ≤15	41	30	14	**29**	**64**	38	17	**40**
15> ≤21	18	22	16	**19**	81	**60**	34	**58**
21> ≤30	12	23	25	**20**	94	83	**59**	**78**
>30	6	17	41	**22**	100	100	100	**100**

Table 3.9 shows the proportion of consumers from each income group who use water within each tariff block of the proposed tariffs. It can be seen that approximately 50% of consumers from each income group use less water than the limit of their respective tariff blocks for the proposed new tariff 1 structure. Similarly approximately 60% of each income group use less water than the limit of their tariff blocks in the proposed new tariff 2 structure.

The table also shows the proportion of consumers in each income group who spill over into tariff blocks not specifically designed for their income level. It can be seen that increasing the size of each block would include a greater proportion of the target group that the block was designed for, as well as a greater proportion of higher income households.

3.11.2. Determining a revenue requirement

A water service provider would generally determine a revenue requirement by modelling the consumption of its consumers. The revenue from sales must equal the cost of sales. A simple model would forecast sales to be the current sales plus a percentage growth. In most cases the consumers would be segmented into different classes, i.e. domestic, institutional, commercial and industrial. The model of sales to domestic consumers may be as simple as average domestic consumption times the number of domestic consumers. More advanced models would segment domestic consumers into income brackets, apply a frequency distribution of monthly bills and possibly apply the price elasticity of demand in calculating the impact on revenue due to tariff changes.

A model of domestic consumers was created for this dissertation to simulate the impact of a proposed tariff change. The domestic consumers were segmented into low, middle and high income groups, with a frequency distribution of monthly bills as determined by the sample of real consumers analysed in **Section 3.7.** It was assumed that the revenue generated by the model consumers using the applicable tariffs from 2002/2003 would cover the costs of delivering water services to these consumers during 2002/2003. With this assumption it was then possible to calculate a revenue requirement for the Ramsey pricing tariff and compare the revenue generated by the old tariff with the revenue generated by the new (Ramsey pricing) tariffs. The model consisted of approximately 3 000 well behaved low, middle and high income households, each group consisting of 1 000 consumers.

3.11.3. Application of the Ramsey pricing formula

The revenue of the water service provider is equal to the sum of bills paid by the individual consumers. Each bill is the sum of kilolitres consumed in each block at the block tariff plus any fixed charges.

The size of each tariff block was assumed as described in Section 3.11.1, and the number of consumers in each increment of consumption was determined from the frequency distribution of monthly bills for the domestic consumers of Durban. The unknown variables that needed to be calculated were the price of each tariff block and fixed charges applied at each step.

These prices were calculated using the Ramsey pricing formula:

$$\frac{\Delta P_1}{\Delta P_2} = \frac{\varepsilon_2}{\varepsilon_1}$$

Where:

$$\Delta P_i = \frac{P_i - C_i}{P_i}$$

P_i = price of i^{th} tariff block

C_i = marginal cost of i^{th} tariff block

ε_i = price elasticity of demand of i^{th} tariff block

Since the marginal cost of water was assumed to be the Umgeni Water bulk tariff $C_1 = C_2 = C_3 =$ R2.28.

From **Table 3.5,** the price elasticity of demand for the income groups is:

ε_1 = price elasticity of low income group = -0.55,

ε_2 = price elasticity of middle income group = -0.14,

ε_3 = price elasticity of high income group = -0.10.

The required prices P_1, P_2 and P_3 were found by an iterative process of:

1. Estimating a value for P_1
2. Calculating P_2 and P_3 using the Ramsey pricing formula
3. Substituting these values into the block tariff structure
4. Calculating the value of a bill for each increment of consumption
5. Multiplying the value of bill for each consumption increment by the number of consumers in that consumption increment
6. Adding all the revenues for each consumption increment to determine the revenue from sales.
7. Comparing the revenue received using the estimated tariff prices with the revenue requirement
8. Adjusting the estimated value of P_1 and recalculating the revenue received until it meets the revenue requirement.

The above procedure was carried out using a spreadsheet.

Fixed charges were determined by a similar procedure to the consumptive charges calculation. In this analysis it was assumed that a fixed charge will apply on entering each new tariff block. Fixed charges are used to cover the cost of providing the service connection to each consumer irrespective of consumption. They are an important source of revenue for the service provider as it provides a certain level of guaranteed revenue to cover the short run fixed cost of providing the service. Fixed charges are often regressive in that they make up a larger proportion of the total bill for low income households than for higher income households. The Ramsey pricing methodology was applied in setting the fixed charges for each block. However it should be noted that in the case of consumptive charges, the short run marginal cost of the service was the floor above which the price for the low income block was set. In the case of the fixed charges, the actual cost of the service connection was relatively high for low income households and the actual difference in cost in serving low income households against high income households did not reflect the differences in income distribution. In order to ensure that the fixed charges were affordable, they were set artificially low for the first block (approximately equal to the existing fixed charge for the first block), and Ramsey pricing was used to determine fixed charges for each higher block. This ensured that fixed charges related to households affordability and willingness to pay, with higher income groups subsidizing the access costs for lower income households

The calculated new tariff structures are presented with the old tariff structure in **Table 3.10**.

Table 3.10: Old and new tariff structures calculated using Ramsey prices.

	Variable charges			Fixed charges		
Tariff Block (kL)	Old tariff (R/kL)	New tariff 1 (R/kL)	New tariff 2 (R/kL)	Old tariff (R)	New tariff 1 (R)	New tariff 2 (R)
0> ≤ 6	0	0	0	0	0	0
6 > ≤ 12	4.57	2.54	2.57	24.94	21.83	22.07
12 > ≤ 15	4.57	3.81	2.57	35.69	29.82	22.07
15 > ≤ 18	4.57	3.81	4.10	35.69	29.82	31.67
18 > ≤ 21	4.57	5.22	4.10	35.69	37.11	31.67
21 > ≤ 27	4.57	5.22	6.01	35.69	37.11	41.31
27 > ≤ 30	4.57	10.44	6.01	35.69	37.11	41.31
>30	9.14	10.44	12.02	35.69	37.11	41.31

Table 3.10 shows that making the pro-poor block larger forces the price for each subsequent block to be higher. This was expected.

The new tariff structures were used to calculate the cost of the monthly water bill according to the consumption increment. This was compared to the existing tariff structure and the cost of providing the service in **Figure 3.10**. The fixed cost component of the service was based on a fixed cost of R46.62 per connection plus R1.08 per kL for a 30kL/month/consumer design capacity of the water supply infrastructure. The variable cost was based on the Umgeni Water bulk tariff and did not take into account non revenue water due to leaks, illegal connections and faulty meters.

It can be observed in **Figure 3.10** that all consumers who use less than 27 kL/month benefited from the new tariff structures. This represented 78% of all consumers. It was also clear that the average bill for those consumers who used between 12 and 18 kL/month would drop significantly, by up to 38% less than the existing tariff structure.

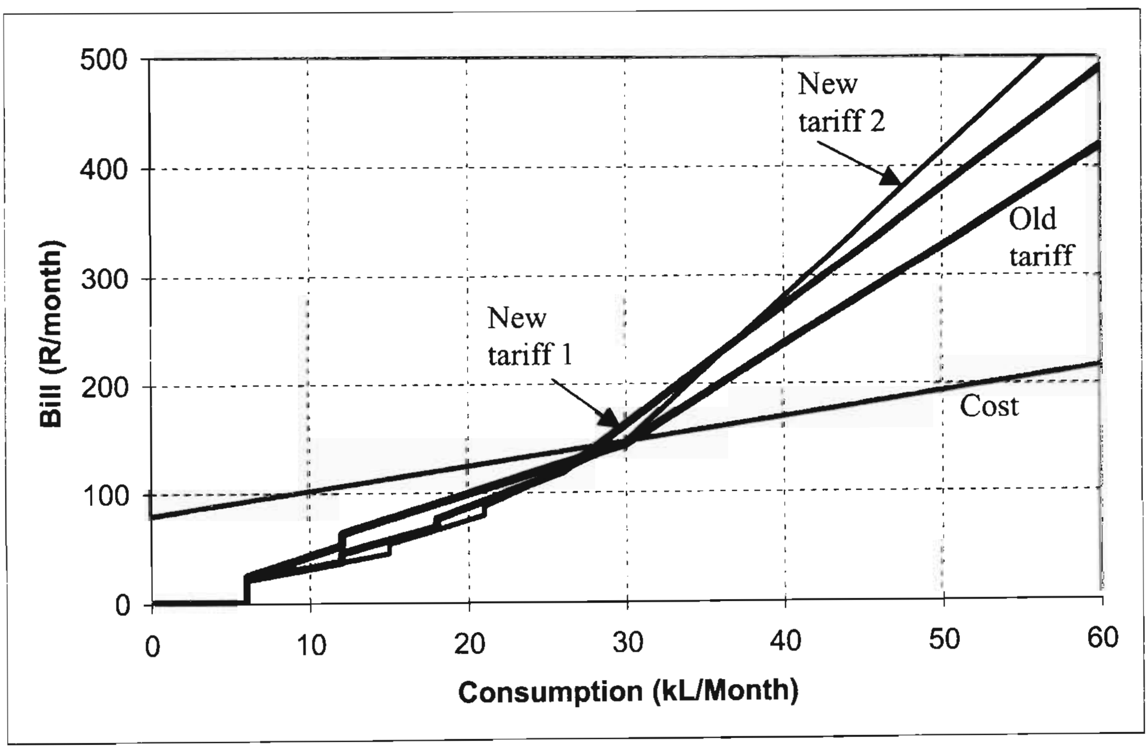

Figure 3.10: Graph showing the change in average bill using the new tariffs as against the old tariff for 2002/2003.

Figure 3.10 also showed that using both the old and new tariffs, the water service provider did not recover the costs of the service from those consumers using less than 27 kL/month. The tariff above 30 kL/month resulted in over recovery, ensuring that overall full cost recovery was achieved. Apart from providing water at a lower cost to households who kept their consumption low, it was also clear that the new tariff structures had a greater under recovery and over recovery than the existing tariff. **Table 3.11** presents the change in revenue received from the different income groups using each of the tariff structures. Less revenue was received from both the low and middle income groups with the new tariff structures. The high income groups provided the cross subsidisation. Note that in all cases the high income groups provided more than 50% of the revenue

Table 3.11: Change in revenue received from each income group with respect to the tariff structure.

	Revenue from each income group			
	Low (R/mth)	Middle (R/mth)	High (R/mth)	Total (R/mth)
Old tariff	70 421	111 329	189 483	371 233
New tariff 1	62 076	107 153	202 033	371 262
New tariff 2	61 566	105 721	203 968	371 255

Table 3.12: Change in revenue received from each consumption bracket in respect to the tariff structure.

	Revenue from each tariff block		
Consumption bracket (kL/mth)	Old tariff (R/mth)	New tariff 1 (R/mth)	New tariff 2 (R/mth)
0> ≤ 6	0	0	0
6 > ≤ 15	48 705	34 901	35 388
15 > ≤ 21	54 651	42 583	43 582
21 > ≤ 30	78 163	77 900	73 851
30 >	189 715	215 879	218 435
Total	371 233	371 262	371 255

Table 3.12 shows in which consumption bracket the revenue was raised. The new tariff structures generate less revenue from the lower consumption brackets than the higher brackets

In all cases the revenue generated from sales above 30 kL/month exceeded 50% of all revenue.

3.12 Welfare impact of the new tariff

The literature on Ramsey pricing suggests that using Ramsey pricing to determine the price of water leads to an optimal welfare distribution effect. Welfare being measured by the consumer surplus; the difference between what a consumer is prepared to pay and what the consumer actually pays.

A model using only three *average* consumers was adopted to calculate the consumer surplus. It was assumed that all low income households have the same demand curve as the average low income household. The same was assumed for middle and high income households. The demand curve for each consumer was described using the linear regression function estimated for each consumer group in **Section 3.8**. This together with the old and new tariffs is presented graphically in **Figure 3.11.**

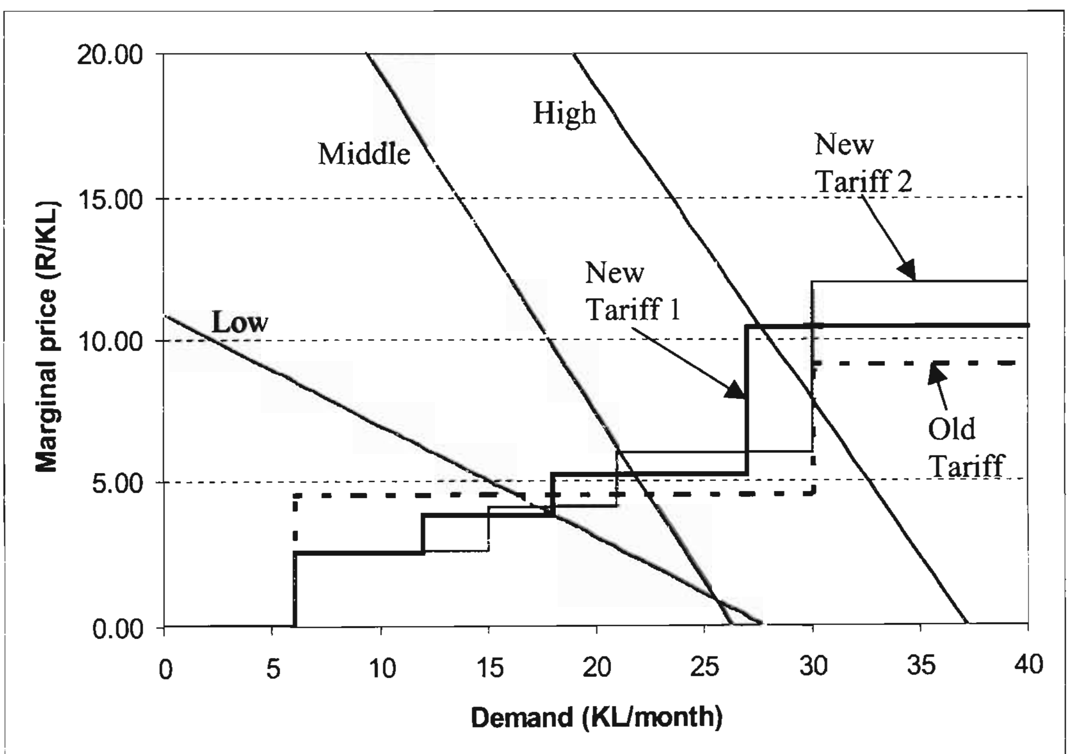

Figure 3.11: Consumer demand curves for low, middle and high income households plotted with the marginal price of water for the old and new tariffs

Note that the consumer demand curve had only been estimated using linear regression for real (year 2000) prices between R2.15 and R4.31. The slope of the curve outside of this range is not known, but has been extrapolated as a straight line so that the consumer surplus can be calculated.

The consumer surplus was calculated for each of the three consumers using the new tariffs and then compared to the consumer surplus found using the old tariff. The results of these calculations are presented in **Table 3.13.**

Table 3.13: Change in consumer surplus for each income group using the new tariff.

	Low income consumer surplus	Middle income consumer surplus	High income consumer surplus	Combined consumer surplus
Old Tariff (Rand/mth)	78.33	301.54	471.92	851.79
New tariff 1 (Rand/mth)	91.11	315.95	481.32	888.38
Change	+12.78	+14.41	+9.40	+36.59
Change (%)	+16.3%	+4.8%	+2.0%	+4.3%
New tariff 2 (Rand/mth)	95.00	322.39	487.07	904.45
Change	+16.67	+20.85	+15.15	+52.66
Change (%)	21.3%	6.9%	3.2%	6.2%

A surprising but not unexpected observation is that all *average* consumers benefited from the change to the new tariff structures. The low income households benefited proportionately more than the higher income groups, but even high income households experienced an increase in consumer surplus. In absolute terms, the middle income group experienced the highest increase in welfare

How is it possible that all three consumers benefited from the new tariff structures? Who was paying for the benefits enjoyed by all? The simplicity of the three consumer model hides the distribution of individual household consumption. **Table 3.14** shows the actual volumes of water sold in each consumption bracket per consumer group.

Table 3.14: Water sales in consumption brackets by consumer group.

Consumption Bracket (kL/mth)	Low income household consumption (kL/mth)	Middle income household consumption (kL/mth)	High income household consumption (kL/mth)	Total household consumption (kL/mth)	Total (%)
0> ≤ 6	8454	8850	8937	26241	6.2
6 > ≤ 15	21741	29457	33375	84573	20.0
15 > ≤ 21	11976	21819	30531	64326	15.2
21 > ≤ 30	10758	24507	46077	81342	19.3
30 >	8400	27285	130332	166017	**39.3**
Total	61329	111918	249252	422499	100.0
Total (%)	**14.5**	26.5	**59.0**	100.0	

From **Table 3.14** it is evident that water purchases in the bracket that exceeds 30 kL per month made up 39 % of all sales. These purchases were made at the penalty tariff. This major contribution to cross subsidisation is not revealed with the simple three consumer model. The new tariff structures lower the price for consumption less than 30 kL per month and increase the tariff for consumption greater than 30 kL per month.

Another observation from **Table 3.14** is that the low income households purchased only 14.5 % of total water sales. The high income group purchased 59 % of all water sales. More than 50% of the high income household water purchases were at the penalty tariff. Less than 15 % of the low income households water purchases were at the penalty tariff.

This may be challenged as being unfair as it placed an unjustifiable burden on high income households. In defence it must be clearly understood that the tariff schedule is applied equitably for all consumers. A high income household could derive the same benefit available to a low income household by using less water. If a high income household chooses to use more water than the average high income consumer then this is because the household believes the value derived from the additional water exceeds the cost, even if this cost includes subsidising lower income households. This is the underlying principle of Ramsey pricing, tax those who are most tolerant of price increases and most able to afford the higher price.

3.13 *Financial and environmental impact of the new tariff*

The same three *average* consumer model used to determine the welfare impact of the new tariffs was also used to investigate the financial and environmental impact of the new tariffs. **Table 3.15** and **Table 3.16** show the change in demand and the change in revenue with the new tariff structures for each of the three consumer groups.

Table 3.15: Change in demand with the new tariffs for average low, middle and high income consumers.

Water Demand	Low income consumer demand	Middle income consumer demand	High income consumer demand	Combined consumer demand
Old Tariff (kL/mth)	15.2	21.6	32.6	69.4
New tariff 1 (kL/mth)	17.9	21.4	27.8	67.1
Change (kL/mth)	+2.7	-0.2	-4.8	-2.3
Change (%)	+18.1	-0.8	-14.8	-3.3
New tariff 2 (kL/mth)	17.2	20.7	30.0	67.9
Change (kL/mth)	+2.0	-0.9	-2.6	-1.5
Change (%)	+13.2	-4.2	-8.0	-2.2

Table 3.16: Change in revenue with the new tariffs for average low, middle and high income consumers.

	Low income consumer revenue	Middle income consumer revenue	High income consumer revenue	Combined consumer revenue
Old Tariff (R/mth)	77.73	106.98	169.13	353.85
New tariff 1 (R/mth)	67.54	92.96	114.88	275.38
Change (R/mth)	-10.20	-14.02	-54.25	-78.47
Change (%)	-13.1	-13.1	-32.1	-22.2
New tariff 2 (R/mth)	63.18	78.17	95.05	236.40
Change (R/mth)	-14.55	-28.81	-74.08	-117.45
Change (%)	-18.7	-26.9	-43.8	-33.2

The same information presented in **Table 3.15** can be obtained by observing the supply and demand curves in **Figure 3.10**. With the new tariff, low income households would increase their consumption and pay less for their monthly water account. Middle income households would reduce their consumption slightly and pay a lot less for water. High income households would reduce their consumption significantly and pay significantly less for water. Overall, for the *average* consumer, the water service provider would experience a 2 to 3 % drop in demand and between 20 and 30 % drop in revenue using one of the new tariff structures.

The small overall reduction in water demand using the new tariffs had a positive environmental conservation impact. The increase in consumption by low income households could be considered to be a negative impact, however since the low income households are responsible for only 14 % of total demand, this increase will have a negligible impact overall, but a major positive impact in terms of personal and community health.

The reduction in revenue generated by the new tariffs presents a warning to the water service provider and explains the increase in welfare calculated for the three consumer model. It must be reiterated that the simplicity of the 3 consumer model hides the total cross subsidisation impact of the new tariffs. However the water service provider would clearly be more vulnerable to a reduction in average consumer demand with the new tariffs in comparison with the old. A decision to move to the Ramsey pricing tariff structure should only be taken once the service provider is confident with the calculated price elasticity of demand and has modelled the impact of price changes with a model that takes the full impact of cross subsidisation into account.

4 Findings

This dissertation set out to determine if Ramsey pricing could be used by the Durban water services department to set affordable and welfare maximising water tariffs. The process required a detailed analysis and understanding of the domestic consumers behaviour when faced with changes in the price of water. This process had in itself made a number of useful findings which need to be noted. This included the statistical properties of the consumer population, the frequency distribution of monthly water demand and the price elasticity of water demand.

The cost of providing water services was an important component of the tariff setting process. This research did not do a detailed analysis of the issues involved, but made certain assumptions regarding marginal costs that were used in determining the proposed tariffs. Two tariff structures were determined using Ramsey pricing principles and compared with the current tariff schedule used by the water service provider. The change in Marshillian welfare between the existing and proposed tariff structures was computed with a simple three consumer model using the average demand functions of three different income groups. The economic and environmental impact of the proposed tariffs were also modelled using the simple three consumer model.

This Chapter of the dissertation presents the findings of each objective addressed in the research. **Section 4.1** presents the water demand characteristics of domestic consumers in Durban. In **Section 4.2**, the estimate of the demand function and associated demand price elasticity of low, middle and high income households is presented. **Section 4.3** presents an estimate of the marginal cost of domestic water supply. Two increasing block tariffs based on Ramsey pricing principles are proposed in **Section 4.4**. The impact on welfare of the proposed tariffs is compared against that of the current tariff by measuring the change in consumer surplus in **Section 4.5**.The financial and environmental impact of the proposed tariffs are also compared.

4.1 *Water demand characteristics of domestic consumers in Durban*

The entire population of 352 000 water consumers supplied by the eThekwini Municipality was segmented into domestic and non-domestic consumers. The domestic consumers were further segmented into single residential or cluster dwelling properties, full pressure and semi-pressure consumers. The full pressure single residential consumers were segmented into those who had unrestricted supply and restricted supply. The unrestricted full pressure domestic consumers, who make up 65% of the entire population of water consumers, were then differentiated by their current level of arrears. A sample of 15000 consumers, representing one third low income, one third middle income and one third high income households was drawn from this population of consumers who were less than three months in arrears with their bill payments. This sample represented well behaved consumers who, through their consumption and payment history, had revealed their willingness to pay for water at different prices between 1996 and 2003. The billing history of the sample consumers was extracted from more than 25 million records. 850 000 observations of monthly water consumption were analysed in the research.

Statistical analysis of the sample showed that there were significant differences in average water demand between the 3 consumer groups (**Table 4.1**). It was also found that in all cases the average demand for water had dropped during the study period. The largest reduction in demand had been in the lowest income group. This suggested that low income groups were most sensitive to real price increases experienced between 1996 and 2003.

Table 4.1: Water demand statistics of the three income groups

Statistic	Low income	Middle income	High income
Average demand 2002/2003 (kL/month)	15.2	21.6	32.6
Change in average demand between 1996 and 2003 (%)	-27	-9	-6
Median demand 2002/2003(kL/month)	12.9	19.8	28.2
Change in median demand between 1996 and 2003 (%)	-30	-6	-3

A frequency distribution of monthly water demand was extracted from the data. The frequency distributions showed that while there were obvious differences in the means and medians of each group, there were also significant overlaps in demand (**Figure 4.1**). When compared year on year, the frequency distributions of the low income group also showed a significant movement towards lower consumption. The same trend was not as evident in the annual frequency distributions of the higher income groups. See Appendix B for details of frequency distribution trends.

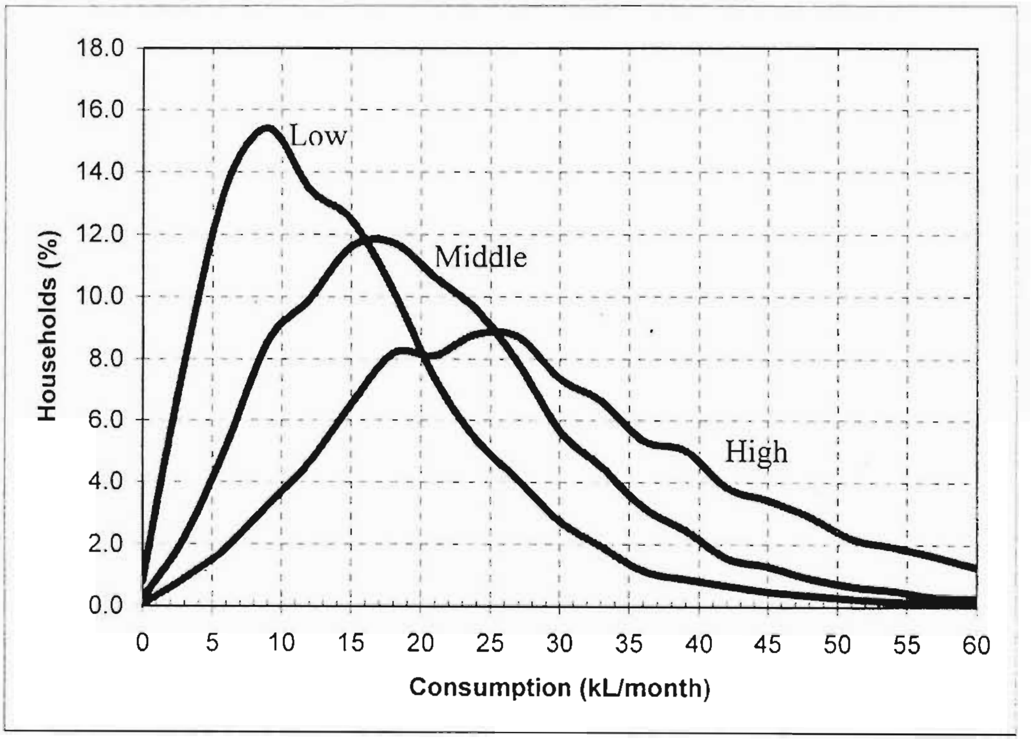

Figure 4.1: Frequency distribution of water demand for low, middle and high income groups in 2002/2003 (n ≈ 4000 consumers per group).

4.2 Estimate of the demand function and associated price elasticity of demand

An essential input into the Ramsey pricing formula is the corresponding price elasticities of demand for each product being taxed. In this case each tariff block was assumed to be a different product, targeted at a different income group. The observed long run price elasticity of water demand for each income group was then used as a proxy for the price elasticity of demand for the targeted tariff block of that income group. A number of regression models were developed to explain changes in monthly water demand with respect to changes in price, temperature and rainfall. In all cases price was the major explanatory variable, with temperature making a minor contribution and rainfall none at all. Both linear and log linear models were developed and tested, with similar results. The most descriptive demand functions of low, middle and high income household water demand are presented in **Table 4.2**.

Table 4.2: Estimated linear and log-linear demand functions for low, middle and high income groups (price based on year 2000 value).

Income group	Form	Demand function	Adjusted R^2
Low	linear	Q = 23.75 -3.07 x Price + 0.13 x Temp + 0.006 x Rain	0.811
	log-linear	$Q = e^{2.69} \times Price^{-0.55} \times Temp^{0.24} \times Rain^{0.01}$	0.869
Middle	linear	Q = 20.98 -1.02 x Price + 0.19 x Temp	0.750
	log-linear	$Q = e^{2.57} \times Price^{-0.14} \times Temp^{0.22}$	0.745
High	linear	Q = 32.92 -1.10 x Price + 0.17 x Temp	0.275
	log-linear	$Q = e^{3.22} \times Price^{-0.10} \times Temp^{0.13}$	0.262

Where:

Q = monthly water demand (kL/month).

Price = real water tariff (indexed on year 2000 rand value) for the 6 to 30 kL/mth tariff block (R).

Temp = average maximum air temperature during calendar month at Durban International Airport (C°).

Rain = total rainfall during calendar month at Durban International Airport (mm)

Both the linear and log-linear demand functions give similar results for estimates of demand within the historical price range between R 2.15 and R 4.31 per kL (year 2000 value). The linear model, being simpler, was used in all the graphical presentations of the consumer demand function.

The estimates of price elasticity for the income groups are presented in **Table 4.3**.

Table 4.3: Estimated price elasticity of water demand for low, middle and high income groups.

Income group	Price elasticity of demand	95% lower bound	95% upper bound
Low	-0.55	-0.50	-0.60
Middle	-0.14	-0.12	-0.16
High	-0.10	-0.06	-0.14

Both the linear and log linear models of water demand provided similar estimates for the price elasticity of demand. There was a small difference between the elasticities estimated for low income households. The elasticity estimated using the log linear model was adopted because the log linear model performed better in terms of its statistical properties. The 95% confidence interval calculated for each of the estimates is quite narrow with very little overlap. This indicates that there is a significant difference in the price elasticity of water demand between the three income groups and that the elasticity is significantly different from 0.

4.3 Marginal costs of domestic water supply

The marginal cost of producing a product is used in the Ramsey pricing formula to set the price of the good. The marginal cost is the floor price, all products are sold at a markup above this price. The annual financial statements of the municipal water department and its bulk water supplier were analysed to determine the appropriate marginal cost of supply. A full analysis of the factors impacting on the marginal cost of supplying one additional kilolitre of water to a consumer was beyond the scope of this report. It was assumed that since most of the water supplied in Durban is gravity fed and does not require additional chemical dosing, the bulk water tariff of Umgeni Water would be a very good estimate of the short run marginal cost of water supply. The bulk water tariff was R2.28 during the 2002/2003 financial year.

Using the bulk water tariff as the price floor ensured that all consumers pay at least the cost of each additional kilolitre of water purchased from the bulk supplier to meet their demand. The fixed overhead costs of the municipal water service provider and the cost of unaccounted for water were met by the price markup on higher consumption level blocks and the incrementing fixed charges levied on higher consumption levels.

4.4 Ramsey pricing tariff structure

An increasing block tariff structure consists of tariff block sizes and tariff block prices. Ramsey pricing calculates the welfare maximizing block price for a given block size. Maximum welfare is dependant on the block sizes which are inputs into the Ramsey pricing formula. The selection of the welfare maximizing block sizes was not dealt with in this research. This will remain a political decision for now. It was decided to propose and compare two different block structures in order to guide the decision makers in their deliberations over the most appropriate block sizes.

The frequency distribution was used to guide the selection of appropriate tariff block sizes. The considerable overlap in demand by consumers in different income groups made the selection of block sizes that targeted specific income groups difficult. The design of the first proposed tariff structure ended the targeted block at the **mean** consumption of the targeted income group. The design of the second tariff structure ended the targeted block at the **average** consumption of the targeted income group. The average consumption was generally 10 to 20 % higher than the mean. The first six kL per month were provided free as required by government regulation, and a penalty block was added after the targeted high income block (**Figure 4.2**). The objective of the penalty tariff was to discourage the wasteful or luxury consumption of water by charging the full economic, social and environmental cost of such luxury consumption and to provide revenue for the cross subsidization of lower income households. The penalty tariff was set at twice the tariff for high income households. An accurate estimate of the full economic, social, environmental and opportunity cost of the luxury consumption was beyond the scope of this report.

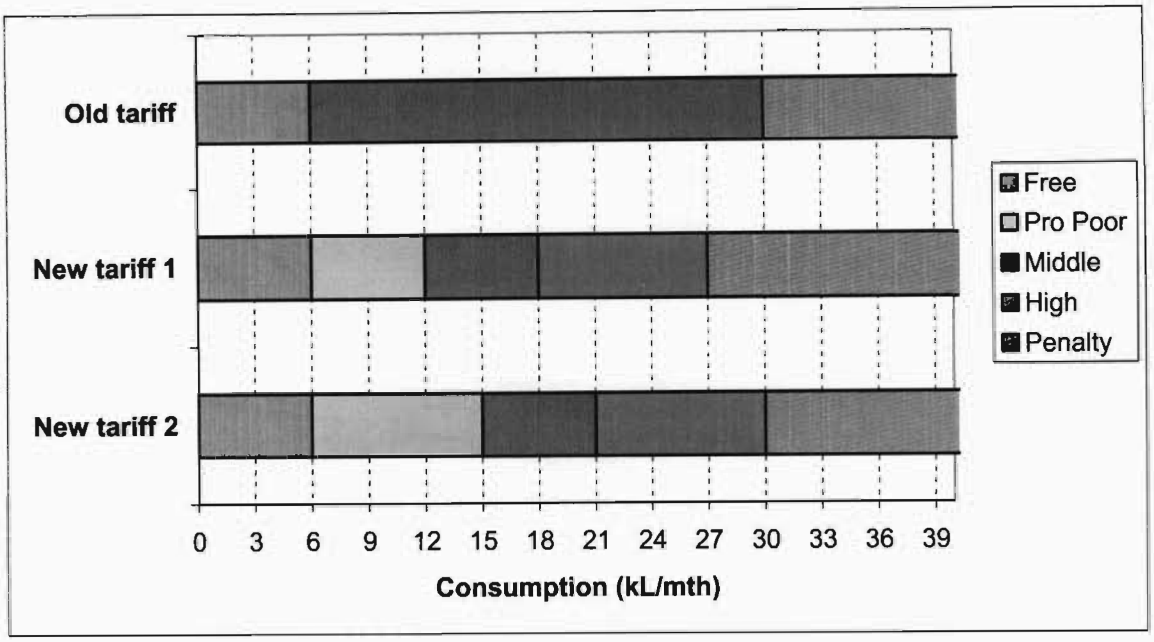

Figure 4.2: Proposed block structures considering the mean and average consumption of low, middle and high income groups

With fixed tariff block sizes, the tariff block prices would depend on a revenue target. A revenue target for the Ramsey pricing tariff schedule was determined by applying the actual tariff schedule for 2002/2003 to a theoretical model of domestic consumers. One thousand consumers were allocated to each income group, with the same frequency distribution of monthly water demand found for the sample of real consumers. The revenue generated using the old tariff was then used as a revenue target for the new tariffs. The calculated price elasticity of water demand for each income group and the short run marginal cost of supply were substituted into the Ramsey pricing formula to find a price setting for each tariff block. The new price schedule was then applied to the theoretical model of consumers to find the revenue generated by the tariff schedule. By adjusting the mark-up percentage of the Ramsey formula it was possible to increase or decrease the revenue received until the target was met. This process led to the tariff schedules and bill charges described and compared with the old tariff in **Figure 4.3**.

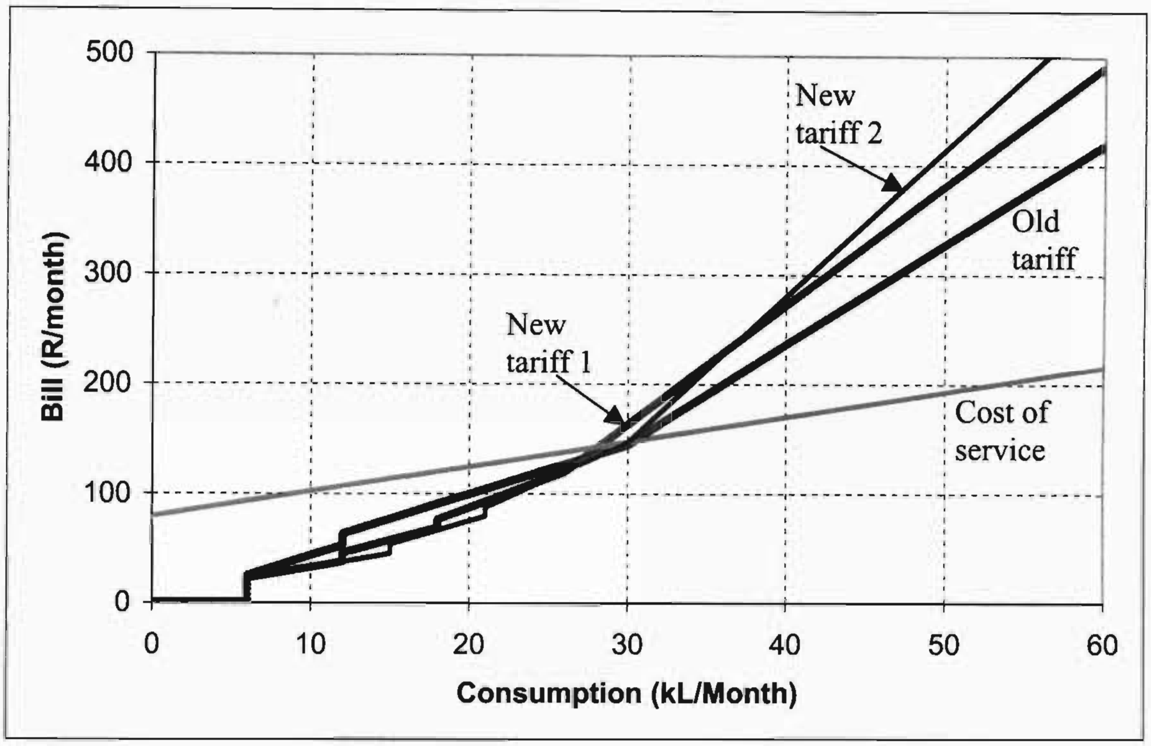

Figure 4.3: Graph showing the change in water bill charges with increasing demand using the old and new tariffs.

Figure 4.3 shows that a substantial portion of consumers, especially in the low and middle income households using between 12 and 18 kL/month would be charged almost 30% less for their water consumption. Households consuming higher volumes of water would pay for the benefits of the lower consuming households. The negatively affected households would either continue to use large amounts of water because they could afford to and believed the benefits they derived from the consumption exceeded the higher costs, or they would reduce their consumption to levels where they would also benefit from the new tariff. The observed price elasticity of demand of the high income households suggested that these households would not reduce their consumption by more than 1% for every 10% that the price was increased. The extent of cross subsidisation with each of the tariff schedules is shown in **Figure 4.4**.

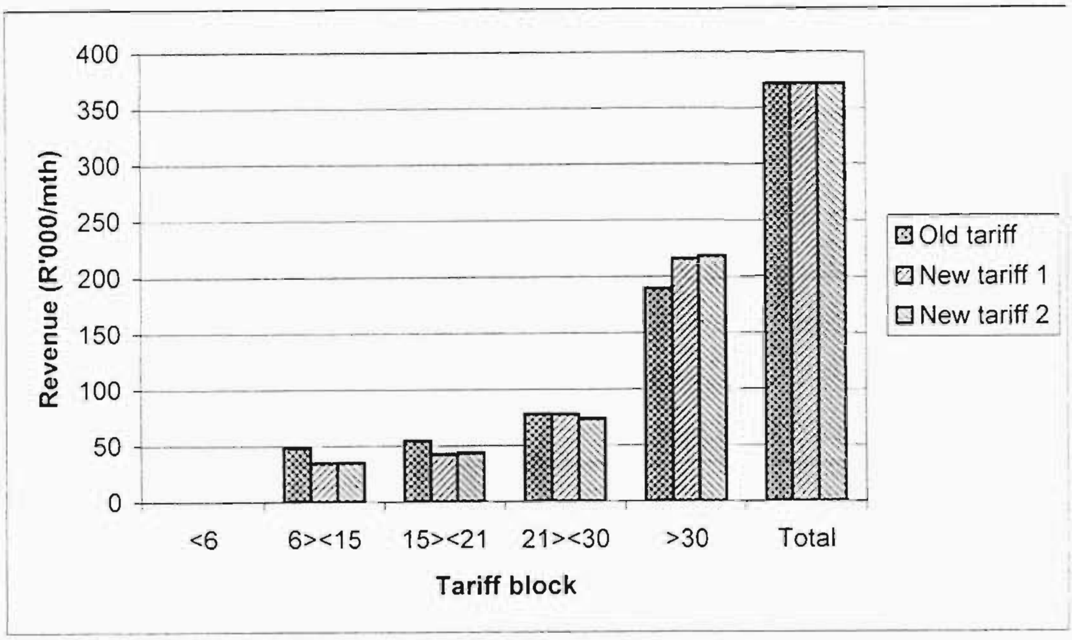

Figure 4.4: Graph showing the change in revenue received from each block with the three tariff schedules

Figure 4.4 shows that in comparison with the old tariff, the two new tariffs collect less revenue from the tariff blocks less than 30 kL per month and a higher amount of revenue from sales greater than 30 kL per month. The revenue received from consumption greater than 30 kL per month is more than 50% of all the revenue received. The total revenue received from all the tariff schedules is the same.

4.5 Welfare impact of the proposed tariff

One of the primary objectives of using Ramsey pricing was to achieve an optimum welfare distribution with the new water tariff. Welfare being measured by the consumer surplus, the difference between what a consumer is prepared to pay and what the consumer actually pays. The observed consumer demand schedule for each income group was assumed to represent what the consumer was willing to pay. The tariff schedule was what the consumer actually paid for each increment of consumption. The area in between the two curves was calculated for both the old and new tariffs for each income group. **Figure 4.5** shows the consumer demand schedules for low, middle and high income households and the marginal prices for the old and new tariff structures. **Table 4.4** shows the result of these calculations and the change in consumer surplus due to the change in tariff structures.

Table 4.4: Change in consumer surplus for each income group using the new tariff.

	Low income consumer surplus	Middle income consumer surplus	High income consumer surplus	Combined consumer surplus
Old Tariff (Rand/mth)	78.33	301.54	471.92	851.79
New tariff 1 (Rand/mth)	91.11	315.95	481.32	888.38
Change	+12.78	+14.41	+9.40	+36.59
Change (%)	+16.3%	+4.8%	+2.0%	+4.3%
New tariff 2 (Rand/mth)	95.00	322.39	487.07	904.45
Change	+16.67	+20.85	+15.15	+52.66
Change (%)	+21.3%	+6.9%	+3.2%	+6.2%

The most significant feature of the new tariffs was that the consumer surplus increased for all income groups. This confirmed the theory that Ramsey pricing can lead to an increase in welfare distribution. Both the proposed new tariffs resulted in a pareto improvement over the old tariff as they increased the welfare of the low income group without reducing the welfare of any other group. The proposed new tariff 2 was a pareto improvement over the proposed new tariff 1 for the same reason. It cannot be stated that either of the proposed tariffs was the pareto efficient tariff. This can only be determined by measuring the consumer surplus arising from a range of changes in both the block size and price of the tariff blocks. In this research only the price was manipulated using Ramsey pricing. Intuition rather than any optimisation process fixed the different block sizes. The development of a model which optimises the block sizes would be highly recommended. The tariffs developed using the assumed block sizes will guide decisions with regards future tariff structures rather than prescribe optimums.

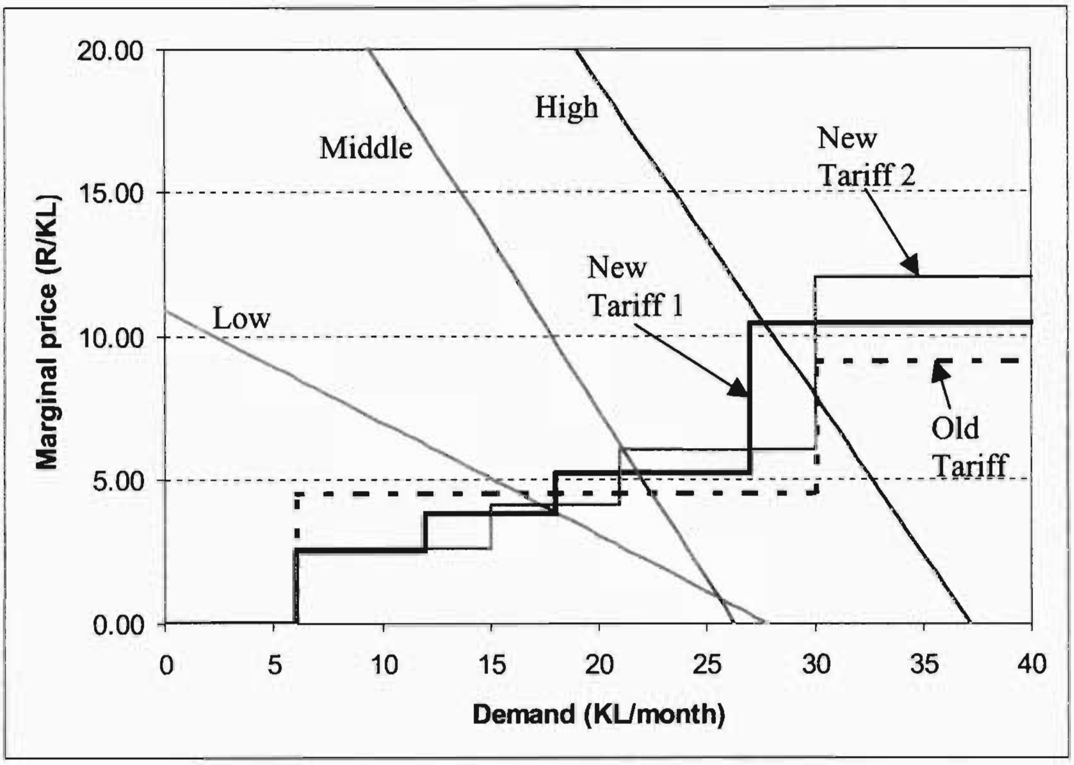

Figure 4.5: Consumer demand curves for low, middle and high income households plotted with the marginal price of water for the old and new tariff structures

Figure 4.5 shows the consumer demand curves and the proposed new tariff structures. It also shows that setting a larger pro-poor block pushes the price up for all subsequent blocks. Setting the size of the blocks too small results in the average consumer in any particular income group using more water than the targeted block for that consumer group. It is clear that the solution to the problem of setting the price of tariff blocks targeted at specific income groups would require multiple iterations of setting block sizes, finding the tariffs that generated the revenue required, and then calculating the resulting consumer surplus. The optimal solution would be the one that maximizes the consumer surplus, or welfare, of the consumers.

The same three consumer model used to determine the welfare impact of the new tariff was also used to investigate the financial and environmental impact of the new tariff. The results can be observed graphically in **Figure 4.5**. With the new tariffs, low income households would increase their consumption by while paying less for their monthly water account. Middle income households will reduce their consumption and pay less for water. High income households would also reduce their consumption and pay less at the end of the month. Overall the water service provider would experience a 2 to 3% drop in demand and between 20 and

30 % drop in revenue from the average consumer using the new tariff structure. The loss in revenue will be made up by sales at the penalty tariff to households that exceed 30 kL per month.

In summary;

- New tariff 2, designed using a larger pro-poor block, resulted in 2 % greater consumer welfare than new tariff 1, designed with a smaller pro-poor blocks, and a 6 % increase in welfare over the old tariff. Both tariffs presented an improvement, but new tariff 2 would be recommended from a social welfare perspective.
- New tariff 1 resulted in a 3.3 % drop in water demand in comparison with the old tariff, and was 1 % point lower than new tariff 2. Both tariffs present an improvement, but new tariff 1 would be recommended from a water conservation perspective
- New tariff 2 resulted in a 33 % drop in sales revenue from consumers using less than 30 kL per month. New tariff 1 resulted in a 22 % drop in revenue from the same consumers. This drop in revenue has to be made up from higher sales revenue from consumers using more than 30 kL per month. Both tariffs place the service providers revenue stream at risk. New tariff 1 would be preferred from a risk averse perspective.

5 Conclusions

The conclusion to this research considers the following questions:

- Does Ramsey pricing address the objectives of setting water tariffs? (**Section 5.1**)
- What risks does Ramsey pricing introduce? (**Section 5.2**)
- Should Ramsey pricing be used in Durban? (**Section 5.3**)

A final comment is made in **Section 5.4** where the findings of the research are evaluated in terms of economic theory and previous research.

5.1 The objectives of setting water tariffs

The increasing block tariff structures developed in this dissertation with Ramsey pricing principles addressed the main objectives of tariff setting for both officials and politicians.

- The proposed new tariffs raised the same revenue as the old tariff, thus addressing the issue of <u>revenue sufficiency</u>.
- The research has shown that high income households use more water than low income households. The proposed tariff structures redistribute income by charging low prices for lower consumption and higher prices for higher consumption
- The tariff structures could be applied equitably across all domestic consumers. Both low and high income households would be charged the same amount if their consumption was the same.
- Each step in the increasing block tariff structures discourages the unnecessary luxury use of water. With informative billing users would respond accordingly, promoting resource conservation and the sustainable use of water.
- The final block of each new tariff was arbitrarily set at twice the tariff of the high income block to encourage water conservation. With more information, this could be set at the full environmental cost of developing water resources ensuring the economic efficiency of the tariff for volumes in excess of reasonable domestic consumption.
- The proposed tariff structures are relatively simple, requiring only minor changes to the existing increasing block tariff to implement

- The proposed tariff structures are also completely transparent. There are no significant legal, administrative or technical issues that would prevent its implementation.

All these objectives are quantifiable and could be achieved with the current increasing block tariff. Applying Ramsey pricing in the increasing block tariff design addressed the subjective issue of fairness. It would be difficult for someone to argue that the proposed tariff was unfair if the tariff design was based on what households were willing to pay as revealed by their historical water purchases. The research has shown that implementing the proposed tariff would result in an improvement in welfare for 75% of all consumers. The tariff could therefore be easily defended, ensuring its public acceptability and political support.

5.2 The risks of Ramsey pricing

Revenue stability is probably the most important issue to be considered before introducing the proposed tariff structure. In **Figure 4.3** it was shown that for both the old and new tariffs, the bills for consumption below 28 kL/month recovered less revenue than the cost of the water supplied. The new tariffs recovered less than the old tariff for these low levels of consumption. This places the water service provider at a greater risk of under recovery with the new tariffs. The figure also showed that the new tariffs recovered more than the cost of the service for consumption greater than 30 kL/month. A decision to implement the new tariffs can only be made with confidence if the decision makers are certain that sufficient revenue will be received from consumers using more than 30 kL/month to cover the costs of the under recovery.

The research found that setting the size of the pro-poor block at either the mean or the average consumption for low income households made little impact on total welfare. It did find that using smaller block sizes had more impact on water conservation and presented less risk of insufficient revenue being collected. A larger pro-poor block raised the price of the pro-poor block and subsequent blocks. The larger pro-poor block had less conservation impact and presented a greater risk of under recovery.

The Ramsey pricing methodology is not complex but needs good estimates of the price elasticity of water demand for different target groups. The Ramsey pricing formula is more sensitive to the ratio between the price elasticities rather than the absolute values. This will allow some flexibility in the methodology adopted for calculating price elasticities. The long run price elasticity of water demand was estimated for this research. The short run price elasticity is known to be less elastic for essential goods. A financial model based on long run price elasticities could result in over recovery in the short term. The financial model used in this research was based on the frequency distribution of 3 000 consumers and ignored the price elasticity of demand. The tariffs calculated in this research will have to be reviewed with a model that takes price elasticity into account before being implemented.

A reasonable estimate of the short run marginal cost of supply is required as this sets the price floor above which the low income or pro-poor tariff must be set. Municipalities that can lower their short run marginal cost can offer lower pro-poor tariffs than municipalities that are tied into a single bulk water supplier like a regional water board. Durban should discuss the restructuring of the bulk water tariff with Umgeni Water. Introducing a two part bulk water supply tariff structure will allow the municipality to offer a lower first block tariff to poor households.

The price elasticity of water demand was estimated for three consumer groups based on the lowest third, middle third and highest third of rateable property values. The financial model assumed there were equal numbers of consumers in each group. This was true for the 2002/2003 financial year but will change with time. Between 10 and 15 thousand low cost houses are planned to be built each year in the eThekwini Municipality over the next ten years. This will increase the number of low income households and their proportion of all water consumers. The financial model will have to accommodate the proportional change in low, middle and high income consumers to remain accurate in forecasting water demand and revenue generated by water sales.

5.3 Ramsey pricing for Durban

Like all municipalities in South Africa, the officials of Durban are under constant pressure to improve service delivery, extend services to previously un-served communities, and ensure that services remain affordable and sustainable. The price set for water services impacts on all these issues. Sufficient revenue must be raised through the sale of water to maintain and improve the quality and quantity of water supplied to existing consumers. Capital loans required for the installation of infrastructure necessary to serve previously unserved communities must be redeemed through future water sales to new consumers. Newly connected consumers must be able to afford the benefits of a piped municipal water supply.

Setting the price of water services involves negotiation between the officials who are primarily concerned with recovering the cost of services, and the elected politicians who are concerned with reaching previously disadvantaged communities with water services that are affordable. Designing an appropriate increasing block tariff structure is not a simple task. There are many variable that need to be set; the number of blocks, the size of each block and the price of each block. Many combinations of blocks and prices can result in a desired revenue target being achieved. It is in all parties interest that a tariff structure is negotiated that will maximise consumer welfare, ensure sufficient revenue is collected to cover the cost of the service, and ensure that water use is efficient and sustainable.

The findings of this research have supported the theory that calculating water tariffs using Ramsey pricing principles can meet revenue requirements and lead to a better distribution of welfare for the municipalities' consumers. Adopting the principle of Ramsey pricing to differentiate the price of blocks will, like the principle of an increasing block tariff structure, allow politicians and officials to focus on more subjective issues during tariff setting negotiations, like setting the size and price of the pro-poor block

The findings of this dissertation could provide decision makers with the confidence needed to take decisions on changing the tariff structure. The consumer demand functions, price elasticity of demand, and frequency distribution of monthly bills should be built into a model that will accurately simulate the change in revenue received due to consumers change in demand with respect to changing price.

The tariffs calculated in this research are not necessarily the optimum welfare-distributing tariffs for Durban. However the tariffs developed using Ramsey pricing have proven to be better than the current tariff from the point of view of welfare distribution. The management of the water services department should consider applying the Ramsey pricing principles during the next round of tariff calculations. The obvious welfare distribution effects will appeal to the political leadership and make a significant impact on making domestic water supply more affordable for poor households.

5.4 Economic theory

The results of the research were expected in terms of modern economic theory. The mean and average water demands, as well as the frequency distribution of water demand found for the different income groups were consistent with the theory of supply and demand. Low income households purchased less water than higher income households. The estimated price elasticity of water demand for the three income groups, as determined by the observed behaviour of the water consumers, supports the theory that purchases that consume a larger portion of income are more price elastic than purchases that consume a smaller portion of income.

It is surprising that similar results are not found in the literature. Most research into the price elasticity of demand has taken place in the USA and Europe. Researchers have struggled to find significant differences in the price elasticities of water demand between different income groups. This has been attributed to the fact that the price of water makes up an insignificant proportion of a households budget (Nieswiadomy and Molina, 1988, pg 10). The major differences in price elasticity have been found between inside and outside water use. Inside water has been found to be less elastic in comparison with outside, or low value luxury use (Veck and Bill, 2000, pg 5.9). This has led to the incorrect assumption that because high income households use more water outdoors, the price elasticity of water demand for a high income household will be higher than that for a lower income household (Moilanen and Schulz, 2002, pg 361, Boland and Whittington, 2000, pg 228). Low income households are assumed to be limited by how much water they can save in the event of price increases.

The research carried out for this dissertation has demonstrated quite clearly that in the case of developing countries with high income differentials, the price elasticity of water demand is significantly higher for low income households in comparison with higher income households. This can be attributed to the fact that with limited budgets and many competing essential goods, if the price of water goes up, consumption must come down or the poor households budget will not balance. An economic reality in the developing world.

6 Recommendations

This dissertation found that using Ramsey pricing principles in setting the price of consumption blocks of water tariff could lead to an improvement in consumer welfare. The research also found that changing the size of the tariff blocks resulted in a trade-off between social, environmental and economic objectives. The findings were based on the output of simple consumer models. It was established that the simple consumer models accounted for either the cross subsidisation effect, or the price elasticity of demand effect, but not both simultaneously. The models could solve for a welfare maximising block price based on a given block size, but could not solve for both the welfare maximising block size and price.

This dissertation has laid the foundation for a welfare maximising tariff model to be developed with Ramsey pricing principles. The Appendices contain summaries of real consumer billing data that could be used to test the model and its impact on welfare. A model should be developed that can use different price elasticities of water demand, frequency distributions of demand, proportion of low, middle and high income households, and marginal price of water supply as input. Additional constraints must be optional, such as the size of a free basic water block, pro-poor block and the price of a penalty tariff.

The development of a model must take into account the work already done in developing water tariff models, especially the Water Supply Services Model (WRC, 1998) and the Free Basic Water Services Planning Model (DWAF, 2002), both developed by the Palmer Development Group and available for download on the internet. The model could be a stand-alone model used with input from the Water Supply Services Model, which focuses of investments required for addressing the services backlog, and provide outputs which are used in the Free Basic Water Services Planning Model. Alternatively, the principles of Ramsey pricing could be incorporated into the existing Free Basic Water Services Planning Model which takes into account all consumers, not just formal residential consumers as was dealt with in this dissertation.

It is highly recommended that the foundation laid by this dissertation is used to develop a tariff model based on Ramsey pricing principles for water service providers in South Africa.

The model could be piloted in Durban using the data contained in the appendixes and then evaluated to determine its applicability in other municipalities.

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8 Appendixes

Appendix A: Sample statistics

A.1 Determining the sample size

The sample size was selected to achieve a desired precision in the estimated statistic (Billings and Jones, 1996, p160). A larger sample would give a more accurate estimate. The sample size was also dependant on the variability of the data observations. If a variable had a high standard deviation then a larger sample was needed to achieve similar statistical accuracy in comparison with a variable with a smaller standard deviation. Walpole and Meyers (1978, pg 197) provided the following formula for determining the number of observations needed to provide the desired degree of accuracy:

$$n = \left(\frac{z_{\alpha/2}\sigma}{e} \right)^2$$

Where:

n = sample size

e = maximum error

$Z_{\alpha/2}$ = Z number corresponding to $\alpha/2$ level of confidence

σ = standard deviation

The research was considering how the average water consumption of low, middle and high income households had decreased over time with increases in tariff. The statistic required was the mean daily consumption during each billing period.

A random sample of 10 000 domestic consumer records was drawn from the database for the month of April 2003, and the standard deviation of the monthly water consumption values was determined. The results are given in **table A1**

Table A1: Statistics for a random sample of 10 000 domestic consumers.

	N (No.)	Minimum (kL/d)	Maximum (kL/d)	Mean (kL/d)	Std. Deviation (kL/d)
Average consumption	10078	0.02	7.90	0.9048	0.68951

A sample was required that would allow the analysis to be 99% confident that the true mean statistic fell within 0.05 kL/d of the estimated mean.

The formula was used with the following variables:

$Z_{\alpha/2}$ = 2.575 (for α = 0.005 Z = 2.575 => 99% confidence)

σ = 0.69

e = 0.05

results in the sample size required being:

$N = [(2.575 \times 0.69)/0.05]^2$ = 1 263 records

Therefore a minimum sample of 1 263 records was required to calculate the mean consumption for a group with the desired level of accuracy.

A random sample of 5000 consumer records was selected from the population for each income group. To ensure the sample represented well behaved domestic consumers, the sample was selected from the population of consumers who were less than 3 months in arrears, had unlimited access to full pressure water supply, were registered domestic water consumers, and lived on a property zoned as single residential .

A.2 Annual and monthly statistics of residential water demand

Table A2: Annual statistics of HIGH Income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Conf. Interval (kL)
1996/1997	34.7	29.1	18.0	23.2	25249	0.38
1997/1998	34.1	28.8	17.1	22.7	45392	0.27
1998/1999	34.9	30.0	16.7	22.4	45315	0.27
1999/2000	34.5	30.0	16.3	22.1	46137	0.27
2000/2001	33.9	29.4	14.6	20.9	46249	0.25
2001/2002	32.8	28.2	13.7	20.2	46227	0.24
2002/2003	32.6	28.2	13.5	20.1	45579	0.24

Table A3: Annual statistics of MIDDLE Income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Conf. Interval (kL)
1996/1997	23.8	21.0	7.4	14.9	23226	0.25
1997/1998	23.2	20.4	6.7	14.1	40097	0.18
1998/1999	23.2	20.7	6.3	13.7	41906	0.17
1999/2000	22.9	20.7	6.0	13.5	48203	0.16
2000/2001	22.4	20.4	5.5	12.9	48710	0.15
2001/2002	21.7	19.8	5.0	12.3	48831	0.14
2002/2003	21.6	19.8	5.2	12.5	47484	0.15

Table A4: Annual statistics of LOW Income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Conf. Interval (kL)
1996/1997	20.9	18.3	6.1	13.5	6675	0.43
1997/1998	20.4	18.0	5.7	13.0	11636	0.31
1998/1999	19.2	16.5	5.6	13.0	21816	0.23
1999/2000	18.3	15.3	5.7	13.1	48247	0.15
2000/2001	16.5	14.1	4.2	11.2	48381	0.13
2001/2002	15.7	13.5	3.8	10.7	48248	0.13
2002/2003	15.2	12.9	3.6	10.4	48320	0.12

Table A5: Annual statistics of ALL Income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Conf. Interval (kL)
1996/1997	28.4	23.7	13.2	19.9	55150	0.22
1997/1998	28.0	23.4	140.3	64.9	97125	0.54
1998/1999	27.3	22.8	42.9	35.9	109037	0.28
1999/2000	25.1	21.0	69.5	45.7	142587	0.31
2000/2001	24.1	20.4	59.4	42.2	143340	0.29
2001/2002	23.3	19.8	55.4	40.7	143306	0.28
2002/2003	22.9	19.5	64.2	43.9	141383	0.30

Table A6
Monthly statistics for high income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Confidence Interval (kL)
Jul-96	35.1	0.9	0.5	0.7	211	0.12
Aug-96	31.3	26.7	14.1	20.6	2492	1.06
Sep-96	38.4	33.6	19.8	24.3	1053	1.93
Oct-96	0.0	0.0	0.0	0.0	0	
Nov-96	124.5	124.5	0.0	0.0	1	0.00
Dec-96	31.8	27.3	13.3	20.0	120	4.69
Jan-97	35.7	30.0	17.0	22.6	3229	1.02
Feb-97	36.4	30.6	19.7	24.3	3772	1.02
Mar-97	34.5	28.8	19.2	24.0	3175	1.10
Apr-97	34.6	29.1	18.1	23.3	3674	0.99
May-97	34.3	29.1	17.3	22.8	4060	0.92
Jun-97	33.4	27.0	17.6	23.0	3075	1.07
Jul-97	33.9	28.5	17.3	22.8	4185	0.91
Aug-97	33.3	27.9	16.5	22.2	4043	0.90
Sep-97	32.7	27.3	16.2	22.1	3014	1.04
Oct-97	34.5	29.1	17.7	23.1	4487	0.89
Nov-97	35.1	29.1	18.8	23.8	3977	0.97
Dec-97	33.6	27.9	16.4	22.2	3156	1.02
Jan-98	34.8	30.0	17.6	23.0	3995	0.94
Feb-98	35.3	30.0	17.2	22.7	3746	0.96
Mar-98	35.2	30.0	18.6	23.6	4246	0.93
Apr-98	32.2	27.3	14.7	21.0	2977	0.99
May-98	33.5	28.2	16.4	22.2	3807	0.93
Jun-98	33.9	28.8	16.3	22.1	3759	0.93
Jul-98	35.9	30.9	17.5	22.9	4640	0.87
Aug-98	31.4	27.3	12.9	19.6	2454	1.02
Sep-98	34.2	29.1	16.0	21.9	4219	0.87
Oct-98	34.8	29.1	16.9	22.5	4064	0.91
Nov-98	35.5	30.0	17.4	22.8	4092	0.92
Dec-98	33.7	29.1	15.3	21.4	3212	0.97
Jan-99	35.0	30.0	16.1	22.0	3829	0.92
Feb-99	35.3	30.0	17.3	22.8	3332	1.02
Mar-99	36.2	31.2	17.7	23.0	4134	0.92
Apr-99	35.9	30.9	18.2	23.4	3419	1.03
May-99	35.7	30.9	17.5	22.9	4154	0.91
Jun-99	33.2	29.1	14.8	21.1	3766	0.88
Jul-99	34.6	30.0	16.3	22.1	4567	0.84
Aug-99	35.0	30.0	15.9	21.8	3368	0.97
Sep-99	35.3	30.0	16.6	22.3	3937	0.91
Oct-99	34.2	30.0	15.1	21.3	3134	0.98
Nov-99	35.8	30.0	18.0	23.2	4440	0.90
Dec-99	34.8	30.0	16.2	22.1	3112	1.02
Jan-00	36.0	30.0	17.1	22.7	4371	0.88
Feb-00	34.5	30.0	16.4	22.2	4083	0.89
Mar-00	35.1	30.0	17.8	23.1	4229	0.92
Apr-00	32.9	28.2	15.2	21.4	2625	1.07
May-00	32.7	28.1	15.7	21.7	4658	0.82
Jun-00	32.0	27.9	13.7	20.3	3613	0.87

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Confidence Interval (kL)
Jul-00	34.1	30.0	15.4	21.5	4117	0.86
Aug-00	35.1	30.0	15.3	21.4	4186	0.85
Sep-00	33.5	29.1	13.9	20.4	3245	0.92
Oct-00	34.5	30.0	15.2	21.4	3682	0.91
Nov-00	33.8	29.1	15.1	21.3	4550	0.81
Dec-00	32.0	27.9	13.2	19.9	2378	1.05
Jan-01	34.0	30.0	14.3	20.7	4883	0.76
Feb-01	33.8	29.4	14.1	20.6	3916	0.85
Mar-01	35.4	30.9	16.0	21.9	4185	0.87
Apr-01	32.5	28.2	13.3	20.0	3063	0.93
May-01	32.9	28.2	14.0	20.5	4478	0.79
Jun-01	33.5	28.8	14.5	20.8	3566	0.90
Jul-01	34.9	30.0	15.7	21.7	3751	0.91
Aug-01	34.0	30.0	14.5	20.9	4226	0.83
Sep-01	32.8	28.2	13.2	19.9	2807	0.97
Oct-01	33.6	29.1	14.6	20.9	4407	0.81
Nov-01	32.5	27.9	13.8	20.3	4783	0.76
Dec-01	29.4	25.5	10.5	17.8	2199	0.98
Jan-02	32.4	27.3	12.6	19.4	4284	0.76
Feb-02	32.2	28.2	12.6	19.5	3907	0.80
Mar-02	31.8	27.0	13.3	20.0	3501	0.87
Apr-02	33.7	29.1	14.5	20.9	4244	0.82
May-02	32.5	27.9	13.6	20.2	4551	0.77
Jun-02	32.1	27.9	12.8	19.6	3567	0.84
Jul-02	32.2	28.2	12.7	19.5	3928	0.80
Aug-02	31.0	27.0	12.2	19.1	3958	0.78
Sep-02	30.3	26.7	11.5	18.6	3413	0.82
Oct-02	32.7	29.1	12.8	19.6	4521	0.75
Nov-02	33.3	28.8	13.6	20.2	4128	0.81
Dec-02	32.3	28.2	12.2	19.1	3341	0.85
Jan-03	33.1	29.1	13.7	20.2	4242	0.80
Feb-03	33.4	29.1	14.4	20.8	3521	0.90
Mar-03	35.6	30.9	16.5	22.2	3493	0.97
Apr-03	32.8	28.2	14.3	20.7	3588	0.89
May-03	32.5	28.2	13.6	20.2	4160	0.81
Jun-03	32.0	27.9	14.0	20.5	3286	0.92

Table A7
Monthly statistics for middle income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Confidence Interval (kL)
Jul-96	20.9	0.9	0.5	0.7	373	0.1
Aug-96	22.4	19.8	6.2	13.6	2550	0.7
Sep-96	24.0	21.0	7.9	15.4	365	2.1
Oct-96	0.0	0.0	0.0	0.0	0	
Nov-96	44.4	44.4	32.0	31.0	2	56.4
Dec-96	22.4	20.7	5.2	12.5	251	2.0
Jan-97	24.9	21.9	7.6	15.1	3050	0.7
Feb-97	24.5	21.3	7.6	15.1	3338	0.7
Mar-97	24.1	21.3	7.7	15.2	3224	0.7
Apr-97	23.7	20.4	7.8	15.3	3321	0.7
May-97	23.9	20.7	7.5	15.0	3463	0.7
Jun-97	23.1	20.4	6.9	14.4	3255	0.7
Jul-97	23.0	20.1	6.7	14.2	3417	0.6
Aug-97	23.0	20.1	7.1	14.6	3413	0.6
Sep-97	22.3	19.8	6.0	13.5	3212	0.6
Oct-97	23.0	20.4	6.7	14.2	3530	0.6
Nov-97	23.3	20.4	6.5	14.0	3338	0.6
Dec-97	23.2	21.0	6.2	13.7	3018	0.6
Jan-98	23.6	21.0	6.4	13.9	3479	0.6
Feb-98	24.4	21.3	7.3	14.8	3190	0.7
Mar-98	23.6	20.4	7.0	14.5	3510	0.6
Apr-98	23.4	20.7	6.7	14.1	3195	0.6
May-98	23.1	20.7	6.5	14.0	3387	0.6
Jun-98	23.0	20.1	6.6	14.0	3408	0.6
Jul-98	23.4	20.4	7.0	14.5	3713	0.6
Aug-98	22.9	20.4	6.2	13.6	3253	0.6
Sep-98	23.1	20.4	6.4	13.8	3547	0.6
Oct-98	23.0	20.7	6.3	13.7	3591	0.6
Nov-98	23.0	20.7	6.1	13.5	3401	0.6
Dec-98	23.2	20.7	6.1	13.5	3386	0.6
Jan-99	23.9	21.3	6.3	13.8	3576	0.6
Feb-99	23.9	21.3	6.3	13.8	3518	0.6
Mar-99	24.1	21.0	7.1	14.5	3327	0.6
Apr-99	23.6	21.0	6.5	14.0	3539	0.6
May-99	22.7	20.4	5.8	13.2	3612	0.6
Jun-99	22.1	19.8	5.3	12.6	3443	0.6
Jul-99	22.4	20.1	6.3	13.7	4349	0.5
Aug-99	22.8	20.4	5.7	13.1	3748	0.6
Sep-99	22.8	20.4	5.9	13.3	4109	0.5
Oct-99	23.0	20.7	6.0	13.5	3877	0.6
Nov-99	23.0	20.7	6.4	13.9	4032	0.6
Dec-99	23.6	21.3	6.3	13.8	3558	0.6
Jan-00	23.8	21.3	6.2	13.6	4504	0.5
Feb-00	23.5	21.0	6.2	13.6	3987	0.6
Mar-00	23.1	20.7	5.9	13.4	4253	0.5

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Confidence Interval (kL)
Apr-00	22.9	20.4	6.2	13.7	3388	0.6
May-00	22.1	19.8	5.7	13.1	4408	0.5
Jun-00	21.9	19.8	5.5	12.8	3990	0.5
Jul-00	22.1	20.4	5.2	12.5	4227	0.5
Aug-00	22.2	20.1	5.1	12.4	4196	0.5
Sep-00	22.5	20.4	5.5	12.8	3784	0.5
Oct-00	22.2	20.1	5.5	12.8	3890	0.5
Nov-00	22.3	20.1	6.0	13.5	4339	0.5
Dec-00	23.3	21.3	6.3	13.7	1962	0.8
Jan-01	22.6	21.0	5.6	13.0	5899	0.4
Feb-01	22.8	20.4	5.8	13.1	4206	0.5
Mar-01	22.8	20.4	5.5	12.9	3985	0.5
Apr-01	22.4	20.4	5.4	12.8	3830	0.5
May-01	21.8	19.8	5.5	12.8	4395	0.5
Jun-01	22.1	20.1	5.2	12.4	3997	0.5
Jul-01	21.9	20.1	5.1	12.4	3902	0.5
Aug-01	21.7	19.8	4.8	12.0	4154	0.5
Sep-01	21.8	20.0	5.0	12.3	3652	0.5
Oct-01	21.5	19.5	5.2	12.5	4177	0.5
Nov-01	21.7	19.8	5.0	12.2	4414	0.5
Dec-01	21.9	20.7	4.8	12.0	3563	0.5
Jan-02	22.1	20.7	4.8	12.1	4273	0.5
Feb-02	21.8	20.1	4.9	12.1	4068	0.5
Mar-02	21.7	19.8	5.0	12.3	4082	0.5
Apr-02	21.7	19.8	5.1	12.3	4167	0.5
May-02	21.2	18.9	5.4	12.7	4409	0.5
Jun-02	21.2	18.9	5.3	12.6	3970	0.5
Jul-02	21.2	19.2	5.1	12.3	4100	0.5
Aug-02	20.8	18.9	5.0	12.3	4279	0.5
Sep-02	21.0	18.9	4.8	12.0	3909	0.5
Oct-02	21.1	19.2	5.0	12.2	4367	0.5
Nov-02	21.5	19.2	5.4	12.7	4189	0.5
Dec-02	21.7	19.8	5.1	12.4	3889	0.5
Jan-03	22.3	20.7	5.4	12.8	4274	0.5
Feb-03	22.3	20.7	5.5	12.8	3963	0.5
Mar-03	22.1	20.4	5.4	12.8	3478	0.6
Apr-03	21.8	19.8	5.1	12.3	3977	0.5
May-03	21.6	19.5	5.1	12.4	4093	0.5
Jun-03	21.5	19.8	5.5	12.9	2966	0.6

Table A8
Monthly statistics for low income residential water demand

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Confidence Interval (kL)
Jul-96	26.7	0.9	0.5	0.7	12	0.5
Aug-96	19.5	17.4	4.8	11.9	897	1.0
Sep-96	21.8	19.2	5.2	12.5	46	4.7
Oct-96	0.0	0.0	0.0	0.0	0	
Nov-96	0.0	0.0	0.0	0.0	0	
Dec-96	24.5	22.5	0.8	4.8	3	7.2
Jan-97	21.7	18.3	7.1	14.6	965	1.2
Feb-97	22.5	19.8	6.3	13.7	926	1.2
Mar-97	21.4	18.3	7.2	14.7	943	1.2
Apr-97	20.7	17.7	5.5	12.9	960	1.1
May-97	20.4	18.0	5.2	12.5	968	1.0
Jun-97	20.1	17.7	6.2	13.7	952	1.1
Jul-97	20.2	17.4	5.9	13.3	970	1.1
Aug-97	19.8	17.4	5.7	13.1	978	1.1
Sep-97	20.1	17.4	5.9	13.3	953	1.1
Oct-97	20.4	17.7	6.1	13.5	983	1.1
Nov-97	20.4	18.0	5.5	12.9	972	1.1
Dec-97	20.1	18.3	4.9	12.1	956	1.0
Jan-98	20.7	18.3	5.7	13.0	980	1.1
Feb-98	21.4	18.9	5.7	13.0	967	1.1
Mar-98	21.1	18.3	5.8	13.2	979	1.1
Apr-98	20.3	17.7	5.9	13.3	955	1.1
May-98	20.3	18.0	5.5	12.9	967	1.1
Jun-98	19.4	17.1	5.2	12.5	976	1.0
Jul-98	19.9	17.1	5.9	13.3	1590	0.9
Aug-98	18.9	16.1	5.0	12.3	1608	0.8
Sep-98	18.7	15.9	5.4	12.7	1677	0.8
Oct-98	19.3	16.5	5.9	13.3	1683	0.8
Nov-98	19.6	16.5	6.1	13.5	1704	0.8
Dec-98	19.8	17.1	5.7	13.1	1521	0.9
Jan-99	19.5	17.7	5.6	12.9	1997	0.7
Feb-99	20.2	18.0	5.5	12.8	1951	0.7
Mar-99	20.0	17.1	6.0	13.5	2075	0.8
Apr-99	19.8	17.1	5.9	13.4	1876	0.8
May-99	17.8	15.0	5.1	12.4	2177	0.7
Jun-99	17.5	15.0	5.0	12.2	1957	0.7
Jul-99	18.4	15.0	6.4	13.8	4407	0.5
Aug-99	18.4	15.6	6.1	13.5	3895	0.6
Sep-99	18.2	15.0	5.9	13.3	4091	0.5
Oct-99	18.6	15.6	5.9	13.3	3738	0.6
Nov-99	18.1	15.0	5.6	12.9	4233	0.5
Dec-99	19.7	16.8	6.1	13.6	3407	0.6
Jan-00	19.4	16.5	6.0	13.4	4474	0.5
Feb-00	19.3	16.5	5.7	13.1	3990	0.5
Mar-00	18.6	15.6	5.6	13.0	4671	0.5

Meter Read Date	Mean (kL)	Median (kL)	Variance (kL)	Std Deviation (kL)	Sample Size (No.)	99% Confidence Interval (kL)
Apr-00	17.8	15.0	5.1	12.4	3469	0.5
May-00	16.6	14.1	4.7	11.9	4140	0.5
Jun-00	16.3	13.8	4.7	11.9	3732	0.5
Jul-00	16.0	13.5	4.2	11.2	4449	0.4
Aug-00	16.0	13.5	4.0	11.0	4198	0.4
Sep-00	16.3	13.5	4.2	11.2	3389	0.5
Oct-00	15.9	13.5	3.8	10.7	4208	0.4
Nov-00	16.1	13.8	4.0	11.0	4093	0.4
Dec-00	17.5	15.0	4.4	11.4	2746	0.6
Jan-01	16.4	15.0	3.8	10.7	5092	0.4
Feb-01	17.3	15.0	4.4	11.4	4218	0.5
Mar-01	17.4	15.0	4.7	11.9	4288	0.5
Apr-01	16.8	14.4	4.6	11.8	3462	0.5
May-01	16.1	13.8	4.1	11.1	4668	0.4
Jun-01	16.1	13.8	4.3	11.3	3570	0.5
Jul-01	15.8	13.5	4.2	11.2	3947	0.5
Aug-01	15.5	13.5	4.0	10.9	4160	0.4
Sep-01	15.5	13.5	3.9	10.8	3650	0.5
Oct-01	15.4	13.2	3.8	10.7	4114	0.4
Nov-01	15.8	13.5	4.0	10.9	4340	0.4
Dec-01	16.2	14.4	3.6	10.4	3064	0.5
Jan-02	16.2	15.0	3.6	10.4	4615	0.4
Feb-02	16.8	15.0	3.9	10.8	3791	0.5
Mar-02	16.1	13.8	3.7	10.6	3983	0.4
Apr-02	15.9	13.5	3.8	10.7	4243	0.4
May-02	14.9	12.6	3.6	10.4	4635	0.4
Jun-02	14.6	12.3	3.5	10.3	3706	0.4
Jul-02	14.4	12.3	3.4	10.0	4071	0.4
Aug-02	14.1	12.0	3.3	10.0	4499	0.4
Sep-02	14.4	12.3	3.5	10.2	3829	0.4
Oct-02	14.8	12.6	3.6	10.4	4460	0.4
Nov-02	15.0	12.9	3.6	10.4	4012	0.4
Dec-02	15.5	13.4	3.6	10.4	3832	0.4
Jan-03	16.2	14.1	3.8	10.7	4440	0.4
Feb-03	16.2	14.4	3.7	10.6	3834	0.4
Mar-03	15.9	13.5	3.7	10.6	3899	0.4
Apr-03	15.8	13.7	3.7	10.6	3978	0.4
May-03	15.2	13.2	3.5	10.3	4057	0.4
Jun-03	14.4	12.0	3.5	10.2	3409	0.4

Appendix B: frequency distributions

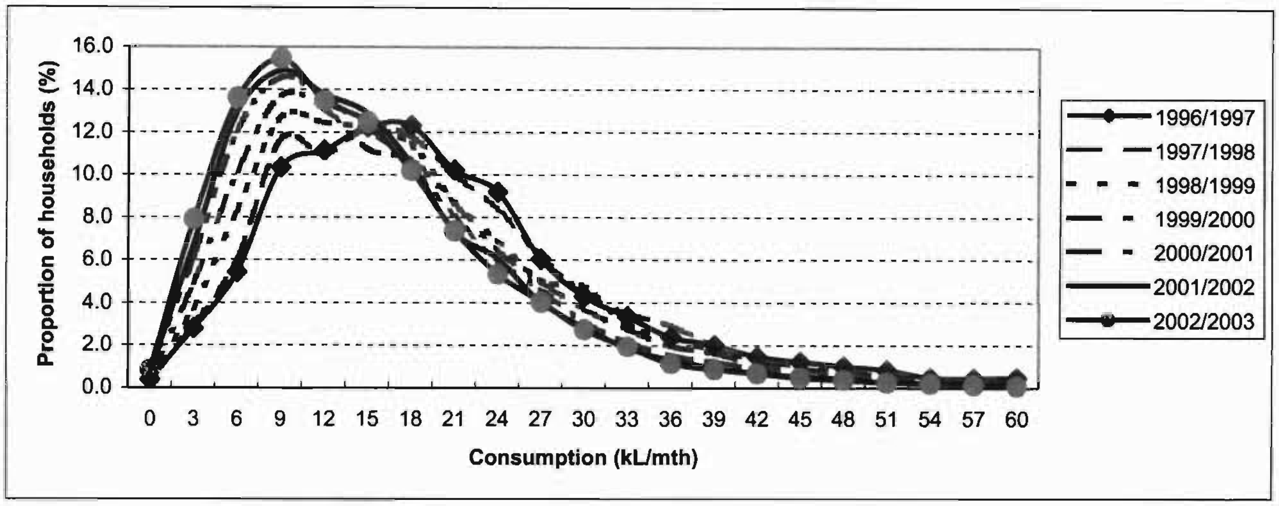

Figure B1: Change in frequency distribution of low income households between 1996 and 2003

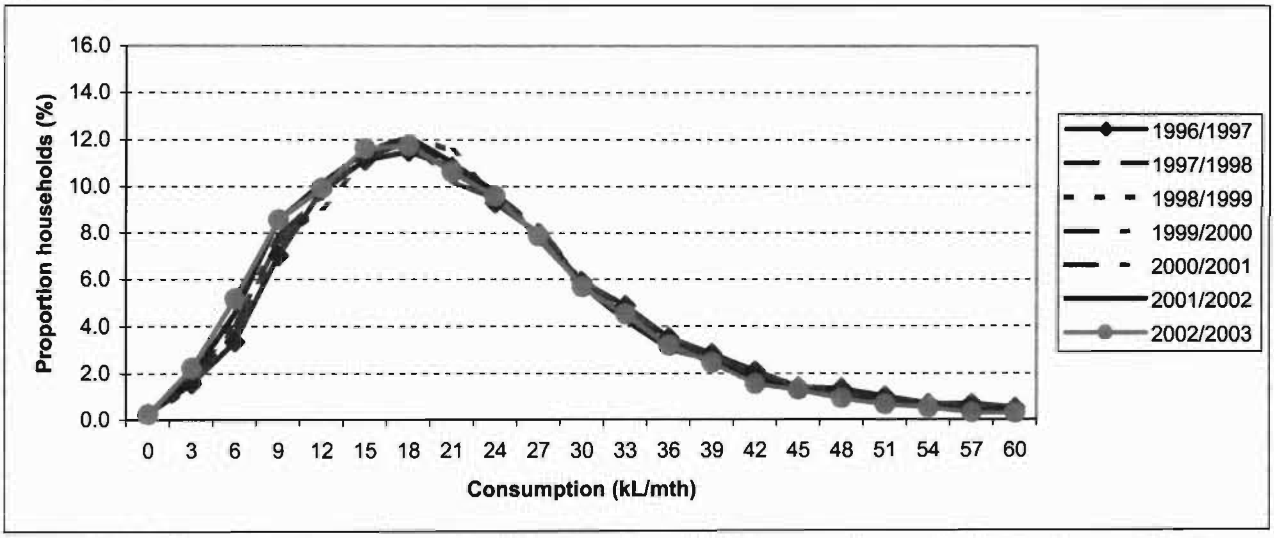

Figure B2: Change in frequency distribution of middle income households between 1996 and 2003

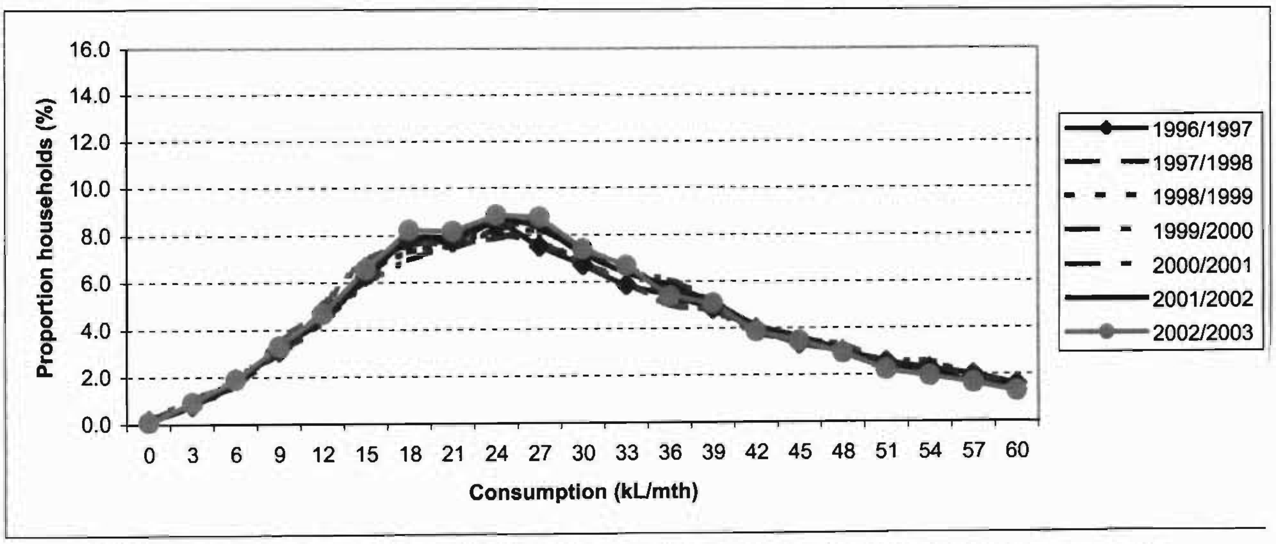

Figure B3: Change in frequency distribution of high income households between 1996 and 2003

Table B1: Frequency distribution of HIGH income households water consumption during the period 1996 to 2003

Bill (kL)	1996/ 1997 (%)	1997/ 1998 (%)	1998/ 1999 (%)	1999/ 2000 (%)	2000/ 2001 (%)	2001/ 2002 (%)	2002/ 2003 (%)	Acc.Sum 2002/2003 (%)
0	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
3	0.8	1.1	0.8	0.8	0.9	0.8	0.9	1.0
6	1.9	1.9	1.7	1.7	1.9	1.7	1.9	2.9
9	3.1	3.5	3.3	2.9	3.0	3.2	3.3	6.1
12	4.8	5.0	4.3	4.3	4.5	4.4	4.6	10.8
15	6.3	6.9	6.3	5.9	6.0	6.2	6.5	17.3
18	7.8	7.5	7.3	6.9	7.8	7.8	8.2	25.5
21	7.7	7.9	7.6	7.6	7.5	7.9	8.1	33.6
24	8.4	8.0	8.1	7.8	8.2	8.6	8.8	42.4
27	7.5	7.6	7.6	8.1	8.5	8.3	8.7	51.1
30	6.7	6.8	7.0	7.2	7.4	7.2	7.4	58.5
33	5.8	5.9	6.7	6.4	6.6	6.4	6.7	65.1
36	5.4	5.0	5.2	6.0	5.6	5.8	5.4	70.5
39	4.8	4.7	5.1	5.1	5.0	5.1	5.0	75.5
42	3.9	3.8	3.8	4.0	4.0	4.1	3.8	79.3
45	3.3	3.5	3.6	3.5	3.4	3.6	3.4	82.8
48	3.0	3.0	2.9	3.2	3.1	3.0	2.9	85.7
51	2.5	2.2	2.5	2.5	2.3	2.3	2.2	87.9
54	2.2	2.2	2.5	2.2	2.2	2.2	1.9	89.8
57	2.0	1.8	1.9	1.9	1.8	1.6	1.6	91.4
60	1.6	1.5	1.6	1.6	1.4	1.4	1.3	92.7
63	1.2	1.2	1.3	1.3	1.2	1.1	1.1	93.8
66	1.1	1.1	1.1	1.2	1.0	1.0	0.8	94.6
69	1.0	1.0	0.9	0.9	0.9	0.9	0.7	95.3
72	0.8	0.8	0.8	0.7	0.7	0.6	0.7	96.0
75	0.7	0.7	0.7	0.8	0.6	0.6	0.6	96.6
78	0.7	0.7	0.7	0.7	0.5	0.6	0.5	97.1
81	0.5	0.5	0.6	0.5	0.5	0.4	0.3	97.4
84	0.4	0.5	0.4	0.5	0.4	0.4	0.3	97.8
87	0.5	0.4	0.4	0.5	0.4	0.3	0.3	98.1
90	0.3	0.3	0.3	0.4	0.3	0.3	0.3	98.4
93	0.3	0.3	0.3	0.3	0.3	0.2	0.2	98.5
96	0.3	0.3	0.3	0.3	0.2	0.2	0.1	98.7
99	0.2	0.2	0.2	0.2	0.2	0.2	0.2	98.9
102	0.2	0.2	0.2	0.2	0.2	0.2	0.1	99.0
105	0.2	0.2	0.2	0.2	0.1	0.1	0.1	99.1
108	0.2	0.2	0.2	0.2	0.1	0.1	0.1	99.2
111	0.2	0.1	0.1	0.2	0.1	0.1	0.1	99.3
114	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.4
117	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.5
120	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.5
123	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.6
126	0.1	0.0	0.1	0.1	0.1	0.1	0.1	99.7
129	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.7
132	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.8
135	0.1	0.0	0.1	0.1	0.1	0.0	0.0	99.8
138	0.0	0.0	0.1	0.0	0.0	0.0	0.0	99.8
141	0.1	0.1	0.0	0.0	0.1	0.1	0.0	99.8
144	0.1	0.0	0.0	0.1	0.1	0.0	0.0	99.9
147	0.1	0.1	0.0	0.0	0.0	0.0	0.0	99.9

Bill (kL)	1996/ 1997 (%)	1997/ 1998 (%)	1998/ 1999 (%)	1999/ 2000 (%)	2000/ 2001 (%)	2001/ 2002 (%)	2002/ 2003 (%)	Acc.Sum 2002/2003 (%)
150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
153	0.0	0.1	0.0	0.0	0.0	0.0	0.0	99.9
156	0.1	0.0	0.0	0.0	0.0	0.0	0.0	99.9
159	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
165	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
168	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
171	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
174	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
177	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Table B2: Frequency distribution of MIDDLE income households water consumption during the period 1996 to 2003

Bill (kL)	1996/ 1997 (%)	1997/ 1998 (%)	1998/ 1999 (%)	1999/ 2000 (%)	2000/ 2001 (%)	2001/ 2002 (%)	2002/ 2003 (%)	Acc.Sum 2002/2003 (%)
0	0.3	0.3	0.1	0.2	0.2	0.2	0.2	0.2
3	1.6	1.7	1.5	1.7	1.9	2.0	2.2	2.4
6	3.4	3.7	3.5	3.9	4.1	4.5	5.2	7.6
9	7.0	7.6	7.6	7.3	7.8	8.6	8.6	16.1
12	9.8	10.0	9.1	9.7	9.7	10.1	9.9	26.0
15	11.1	11.2	11.1	11.1	11.3	11.5	11.6	37.6
18	11.5	11.9	12.1	12.0	11.9	12.1	11.7	49.4
21	10.8	10.2	11.5	10.7	11.0	11.0	10.6	60.0
24	9.3	9.4	9.6	9.6	9.8	9.8	9.6	69.6
27	8.0	7.8	8.0	8.3	8.2	7.7	7.8	77.4
30	5.9	6.1	6.1	6.0	6.0	5.7	5.7	83.1
33	4.9	4.6	4.7	4.8	4.5	4.3	4.5	87.6
36	3.5	3.3	3.3	3.5	3.4	3.1	3.2	90.8
39	2.8	2.7	2.8	2.8	2.7	2.5	2.5	93.2
42	2.1	2.0	1.8	1.9	1.9	1.7	1.6	94.8
45	1.4	1.4	1.5	1.5	1.4	1.3	1.3	96.1
48	1.3	1.2	1.2	1.1	1.1	0.9	0.9	97.0
51	1.0	0.8	0.9	0.8	0.7	0.7	0.7	97.7
54	0.7	0.8	0.7	0.7	0.6	0.5	0.5	98.2
57	0.7	0.6	0.6	0.5	0.5	0.4	0.3	98.5
60	0.5	0.5	0.4	0.4	0.3	0.3	0.3	98.8
63	0.4	0.4	0.4	0.3	0.2	0.2	0.2	99.1
66	0.4	0.3	0.2	0.2	0.2	0.2	0.2	99.2
69	0.2	0.3	0.2	0.2	0.1	0.2	0.1	99.3
72	0.2	0.2	0.1	0.2	0.1	0.1	0.1	99.4
75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.5
78	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.6
81	0.1	0.1	0.1	0.1	0.1	0.1	0.1	99.7
84	0.1	0.1	0.1	0.1	0.0	0.0	0.1	99.7
87	0.1	0.1	0.1	0.1	0.0	0.0	0.0	99.8
90	0.0	0.1	0.1	0.1	0.0	0.0	0.0	99.8
93	0.1	0.0	0.0	0.0	0.0	0.0	0.0	99.8
96	0.1	0.1	0.0	0.0	0.0	0.0	0.0	99.8
99	0.1	0.1	0.0	0.0	0.0	0.0	0.0	99.8
102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.8
105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
108	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
114	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
117	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
123	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
126	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
129	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
141	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
144	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
147	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Table B3: Frequency distribution of LOW income households water consumption during the period 1996 to 2003

Bill (kL)	1996/ 1997 (%)	1997/ 1998 (%)	1998/ 1999 (%)	1999/ 2000 (%)	2000/ 2001 (%)	2001/ 2002 (%)	2002/ 2003 (%)	Acc.Sum 2002/2003 (%)
0	0.4	0.4	0.4	0.5	0.7	0.7	0.8	0.8
3	2.8	3.0	3.8	4.9	6.1	6.8	7.9	8.7
6	5.4	6.0	8.3	10.1	12.1	13.0	13.6	22.3
9	10.3	11.7	12.7	13.7	14.5	14.9	15.4	37.7
12	11.1	11.0	12.4	13.0	13.6	13.8	13.4	51.2
15	12.3	12.2	12.2	11.2	12.2	12.9	12.5	63.6
18	12.3	11.8	11.4	10.7	10.4	10.5	10.2	73.8
21	10.2	10.0	8.7	8.6	8.0	7.3	7.4	81.2
24	9.2	8.4	6.9	6.5	6.0	6.1	5.4	86.5
27	6.1	6.2	5.0	5.0	4.6	4.1	4.1	90.6
30	4.3	4.4	4.8	3.7	3.1	2.9	2.7	93.4
33	3.4	3.5	3.0	2.8	2.2	1.9	1.9	95.3
36	2.4	3.0	2.4	2.0	1.5	1.3	1.2	96.5
39	2.0	2.0	1.8	1.7	1.2	1.0	0.9	97.3
42	1.5	1.3	1.4	1.1	0.9	0.7	0.7	98.0
45	1.2	0.9	1.1	0.9	0.6	0.5	0.5	98.5
48	1.0	0.8	0.8	0.7	0.5	0.4	0.4	98.9
51	0.8	0.7	0.5	0.5	0.4	0.3	0.3	99.2
54	0.5	0.4	0.4	0.4	0.3	0.2	0.2	99.3
57	0.5	0.4	0.3	0.3	0.2	0.2	0.1	99.5
60	0.5	0.3	0.3	0.3	0.2	0.1	0.1	99.6
63	0.3	0.3	0.2	0.2	0.1	0.1	0.1	99.7
66	0.3	0.2	0.2	0.2	0.1	0.1	0.0	99.7
69	0.2	0.2	0.1	0.1	0.1	0.1	0.0	99.7
72	0.1	0.2	0.1	0.1	0.1	0.0	0.0	99.8
75	0.2	0.1	0.1	0.1	0.0	0.0	0.0	99.8
78	0.1	0.1	0.1	0.1	0.0	0.0	0.0	99.8
81	0.0	0.1	0.1	0.1	0.0	0.0	0.0	99.9
84	0.0	0.0	0.1	0.1	0.0	0.0	0.0	99.9
87	0.0	0.1	0.1	0.1	0.0	0.0	0.0	99.9
90	0.1	0.0	0.1	0.0	0.0	0.0	0.0	99.9
93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
108	0.1	0.0	0.0	0.0	0.0	0.0	0.0	100.0
111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
114	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
117	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Total	100	100	100	100	100	100	100	

Appendix C: Regression data

Meter Read Date	Low Inc. Mean demand (kL/Month)	Middle Inc. Mean demand (kL/Month)	High Inc. Mean demand (kL/Month)	Max Daily Temp (C°)	Monthly Rainfall (mm)	Nominal Tariff 6-30 kL (R/kL)	Nominal Tariff >30 kL (R/kL)	CPI	Real Tariff 6-30 kL (R/kL)	Real Tariff >30 kL (R/kL)
Jul-96	26.7	20.9	35.1	20.7	261.4	1.77	2.22	82.5	2.15	2.69
Aug-96	19.5	22.4	31.3	21.9	12.7	1.77	2.22	82.5	2.15	2.69
Sep-96	21.8	24.0	38.4	23.3	22.9	1.77	2.22	82.5	2.15	2.69
Oct-96	22.5*	23.2*	35.0*	23.8	120.8	1.77	2.22	82.5	2.15	2.69
Nov-96	22.5*	23.2*	35.0*	25.8	72.7	1.77	2.22	82.5	2.15	2.69
Dec-96	24.5	22.4	31.8	27.7	72.7	1.77	2.22	82.5	2.15	2.69
Jan-97	21.7	24.9	35.7	27.9	187.1	1.77	2.22	82.5	2.15	2.69
Feb-97	22.5	24.5	36.4	27.6	99.5	1.77	2.22	82.5	2.15	2.69
Mar-97	21.4	24.1	34.5	27.1	59.6	1.77	2.22	82.5	2.15	2.69
Apr-97	20.7	23.7	34.6	24.9	167.9	1.77	2.22	82.5	2.15	2.69
May-97	20.4	23.9	34.3	23.2	40.5	1.77	2.22	82.5	2.15	2.69
Jun-97	20.1	23.1	33.4	22.7	89.4	1.77	2.22	82.5	2.15	2.69
Jul-97	20.2	23.0	33.9	21.6	159.2	2.13	3.19	87.0	2.45	3.67
Aug-97	19.8	23.0	33.3	23.6	16.6	2.13	3.19	87.0	2.45	3.67
Sep-97	20.1	22.3	32.7	23.1	71.2	2.13	3.19	87.0	2.45	3.67
Oct-97	20.4	23.0	34.5	24.3	151.3	2.13	3.19	87.0	2.45	3.67
Nov-97	20.4	23.3	35.1	23.6	277.2	2.13	3.19	87.0	2.45	3.67
Dec-97	20.1	23.2	33.6	26.1	71.3	2.13	3.19	87.0	2.45	3.67
Jan-98	20.7	23.6	34.8	27.6	93.3	2.13	3.19	87.0	2.45	3.67
Feb-98	21.4	24.4	35.3	28.2	158.3	2.13	3.19	87.0	2.45	3.67
Mar-98	21.1	23.6	35.2	27.1	83.8	2.13	3.19	87.0	2.45	3.67
Apr-98	20.3	23.4	32.2	26.4	237.4	2.13	3.19	87.0	2.45	3.67
May-98	20.3	23.1	33.5	24.5	52.2	2.13	3.19	87.0	2.45	3.67
Jun-98	19.4	23.0	33.9	23.1	0.1	2.13	3.19	87.0	2.45	3.67
Jul-98	19.9	23.4	35.9	23.2	22.9	2.53	5.06	94.5	2.68	5.35
Aug-98	18.9	22.9	31.4	23.0	69.4	2.53	5.06	94.5	2.68	5.35

Meter Read Date	Low Inc. Mean demand (kL/Month)	Middle Inc. Mean demand (kL/Month)	High Inc. Mean demand (kL/Month)	Max Daily Temp (C°)	Monthly Rainfall (mm)	Nominal Tariff 6-30 kL (R/kL)	Nominal Tariff >30 kL (R/kL)	CPI	Real Tariff 6-30 kL (R/kL)	Real Tariff >30 kL (R/kL)
Sep-98	18.7	23.1	34.2	23.5	25.5	2.53	5.06	94.5	2.68	5.35
Oct-98	19.3	23.0	34.8	24.3	64.5	2.53	5.06	94.5	2.68	5.35
Nov-98	19.6	23.0	35.5	26.4	106.4	2.53	5.06	94.5	2.68	5.35
Dec-98	19.8	23.2	33.7	26.5	132.6	2.53	5.06	94.5	2.68	5.35
Jan-99	19.5	23.9	35.0	29.0	94.0	2.53	5.06	94.5	2.68	5.35
Feb-99	20.2	23.9	35.3	28.8	239.3	2.53	5.06	94.5	2.68	5.35
Mar-99	20.0	24.1	36.2	29.1	44.2	2.53	5.06	94.5	2.68	5.35
Apr-99	19.8	23.6	35.9	27.8	36.7	2.53	5.06	94.5	2.68	5.35
May-99	17.8	22.7	35.7	24.8	36.5	2.53	5.06	94.5	2.68	5.35
Jun-99	17.5	22.1	33.2	24.3	74.4	2.53	5.06	94.5	2.68	5.35
Jul-99	18.4	22.4	34.6	23.6	3.5	2.89	5.78	97.1	2.98	5.95
Aug-99	18.4	22.8	35.0	24.3	12.2	2.89	5.78	97.1	2.98	5.95
Sep-99	18.2	22.8	35.3	24.0	74.1	2.89	5.78	97.1	2.98	5.95
Oct-99	18.6	23.0	34.2	24.3	195.9	2.89	5.78	97.1	2.98	5.95
Nov-99	18.1	23.0	35.8	26.5	59.1	2.89	5.78	97.1	2.98	5.95
Dec-99	19.7	23.6	34.8	27.5	291.8	2.89	5.78	97.1	2.98	5.95
Jan-00	19.4	23.8	36.0	27.2	181.7	2.89	5.78	97.1	2.98	5.95
Feb-00	19.3	23.5	34.5	28.7	157.3	2.89	5.78	97.1	2.98	5.95
Mar-00	18.6	23.1	35.1	28.1	148.8	2.89	5.78	97.1	2.98	5.95
Apr-00	17.8	22.9	32.9	25.3	63.2	2.89	5.78	97.1	2.98	5.95
May-00	16.6	22.1	32.7	23.4	167.5	2.89	5.78	97.1	2.98	5.95
Jun-00	16.3	21.9	32.0	23.7	3.8	2.89	5.78	97.1	2.98	5.95
Jul-00	16.0	22.1	34.1	22.8	20.2	3.27	6.54	103.6	3.16	6.31
Aug-00	16.0	22.2	35.1	24.1	17.7	3.27	6.54	103.6	3.16	6.31
Sep-00	16.3	22.5	33.5	23.6	62.8	3.27	6.54	103.6	3.16	6.31
Oct-00	15.9	22.2	34.5	23.4	60.2	3.27	6.54	103.6	3.16	6.31
Nov-00	16.1	22.3	33.8	25.7	142.0	3.27	6.54	103.6	3.16	6.31
Dec-00	17.5	23.3	32.0	27.1	124.5	3.27	6.54	103.6	3.16	6.31
Jan-01	16.4	22.6	34.0	27.9	65.5	3.27	6.54	103.6	3.16	6.31
Feb-01	17.3	22.8	33.8	28.3	77.4	3.27	6.54	103.6	3.16	6.31

Meter Read Date	Low Inc. Mean demand (kL/Month)	Middle Inc. Mean demand (kL/Month)	High Inc. Mean demand (kL/Month)	Max Daily Temp (C°)	Monthly Rainfall (mm)	Nominal Tariff 6-30 kL (R/kL)	Nominal Tariff >30 kL (R/kL)	CPI	Real Tariff 6-30 kL (R/kL)	Real Tariff >30 kL (R/kL)
Mar-01	17.4	22.8	35.4	28.9	43.4	3.27	6.54	103.6	3.16	6.31
Apr-01	16.8	22.4	32.5	25.6	90.1	3.27	6.54	103.6	3.16	6.31
May-01	16.1	21.8	32.9	25.5	12.5	3.27	6.54	103.6	3.16	6.31
Jun-01	16.1	22.1	33.5	25.0	0.1	3.27	6.54	103.6	3.16	6.31
Jul-01	15.8	21.9	34.9	23.5	45.3	4.25	8.50	108.3	3.92	7.85
Aug-01	15.5	21.7	34.0	24.0	0.3	4.25	8.50	108.3	3.92	7.85
Sep-01	15.5	21.8	32.8	23.5	145.4	4.25	8.50	108.3	3.92	7.85
Oct-01	15.4	21.5	33.6	24.8	171.3	4.25	8.50	108.3	3.92	7.85
Nov-01	15.8	21.7	32.5	26.2	191.2	4.25	8.50	108.3	3.92	7.85
Dec-01	16.2	21.9	29.4	27.0	142.9	4.25	8.50	108.3	3.92	7.85
Jan-02	16.2	22.1	32.4	28.4	155.8	4.25	8.50	108.3	3.92	7.85
Feb-02	16.8	21.8	32.2	27.4	154.7	4.25	8.50	108.3	3.92	7.85
Mar-02	16.1	21.7	31.8	28.4	21.3	4.25	8.50	108.3	3.92	7.85
Apr-02	15.9	21.7	33.7	27.2	162.6	4.25	8.50	108.3	3.92	7.85
May-02	14.9	21.2	32.5	25.2	3.3	4.25	8.50	108.3	3.92	7.85
Jun-02	14.6	21.2	32.1	23.3	23.8	4.25	8.50	108.3	3.92	7.85
Jul-02	14.4	21.2	32.2	23.0	151.5	5.21	10.42	121.0	4.31	8.61
Aug-02	14.1	20.8	31.0	22.8	53.9	5.21	10.42	121.0	4.31	8.61
Sep-02	14.4	21.0	30.3	23.6	43.6	5.21	10.42	121.0	4.31	8.61
Oct-02	14.8	21.1	32.7	25.3	32.4	5.21	10.42	121.0	4.31	8.61
Nov-02	15.0	21.5	33.3	25.3	64.2	5.21	10.42	121.0	4.31	8.61
Dec-02	15.5	21.7	32.3	27.5	113.3	5.21	10.42	121.0	4.31	8.61
Jan-03	16.2	22.3	33.1	28.0	102.1	5.21	10.42	121.0	4.31	8.61
Feb-03	16.2	22.3	33.4	29.9	15.7	5.21	10.42	121.0	4.31	8.61
Mar-03	15.9	22.1	35.6	29.1	96.3	5.21	10.42	121.0	4.31	8.61
Apr-03	15.8	21.8	32.8	27.1	121.8	5.21	10.42	121.0	4.31	8.61
May-03	15.2	21.6	32.5	24.5*	47.3*	5.21	10.42	121.0	4.31	8.61
Jun-03	14.4	21.5	32.0	23.7*	27.5*	5.21	10.42	121.0	4.31	8.61

*** Missing data interpolated**

Appendix D: Glossary

Average cost	Total cost of production divided by the total number of units supplied
Full pressure	Conventional metered water supply directly from a municipal water main without the intervention of a break pressure tank.
Limited connection	A flow restricting device is installed on the water supply connection to reduce consumption. Normally a sanction imposed for non payment of water account.
Long run marginal cost	The cost of providing the next or last unit in the long run, that is including investments in capital infrastructure to increase capacity.
Marginal cost	The additional cost of production to produce one more unit.
Market clearing price	The price at which quantity demanded equals quantity supplied, so that there are no unsatisfied buyers or sellers.
Multi residential	Residential properties which consist of a cluster of houses on a single property. Ie block of flats or housing complexes.
Nominal price	The actual price paid for a good at the time of purchase.
Pareto efficiency	It is not possible to increase overall welfare without causing some individuals in society to become poorer.
Private good	Goods which are exclusive, i.e. if used by one person cannot be used by another, for example a pair of shoes.
Producer surplus	Income received in excess of the cost of production, i.e. profits.
Public good	Goods which are non exclusive, ie once it is available, no one can be excluded from enjoying the benefits of its use, for example street lights.
Real price	The nominal price of a good multiplied by the consumer price index (CPI) to give a real (indexed) price based on the actual price at a specified time in the past.

Revenue cost constraint	The revenue received through the sale of water must equal the cost of delivering the service, i.e. breakeven pricing, making neither a profit or deficit
Revenue sufficiency	Sufficient revenue must be raised through the sale of water to cover the cost of the service
Semi pressure	Metered water supply from a break pressure tank connected to the municipal water main.
Shack farming	A situation where a home owner constructs single roomed dwellings at the back of his property and rents them out.
Short run marginal cost	The cost of providing the next or last unit while keeping the level of fixed investment constant
Single residential	Residential properties which consist of a single free standing house.
Utility	The satisfaction a consumer receives from consuming a commodity.
Well behaved consumer	A consumer who is more than three months in arrears is assumed to be consuming more water than they are willing to pay for and is therefore **not** a well behaved consumer.