MODELLING DOMESTIC WATER TARIFFS

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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 socio-political objectives. In South Africa, increasing block tariffs are prescribed by regulations under the Water Services Act of 1997 to address problems of unequal income distribution and provide fair access to water.

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 principles were applied to the problem using the domestic water consumers in Durban as a case study.

The water demand characteristic of low, middle and high income households 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 was proposed and compared with the current increasing block tariff applied in Durban.

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.

INTRODUCTION

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.

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 L tank at each shack 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 L tank effectively provided each household with 6 kL free water per month.

According to the Census 2001 statistics, there are approximately 3.1 million people living within the eThekwini Municipality (the further enlarged Durban Metropolitan Municipality) boundary (1). 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 (1).

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 maximisation under a revenue cost constraint (2). Bös demonstrates how the Ramsey formula reduces to an inverse elasticity rule for public utilities applying peak load pricing (3). 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.

DEMAND ELASTICITY

The elasticity of water demand with price was estimated (4) by examining the historic water billing records of consumers.

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. *Well behaved* consumers are those that were actually paying for the water they were consuming.

The water billing database was joined to the municipal property valuation roll (April 2003). Single residences with a valuation of greater than R 1.2 million and less than R 1 000 were excluded. The 291 000 properties were split into 3 equal proportions representing low, middle and high-income households. The breakpoint for low-income households was all properties valued at less than R 56 000, while the break for high-income households was above R 154 400. The database was further modified by only considering *well behaved consumers*. Further checks were undertaken to eliminate corrupt data.

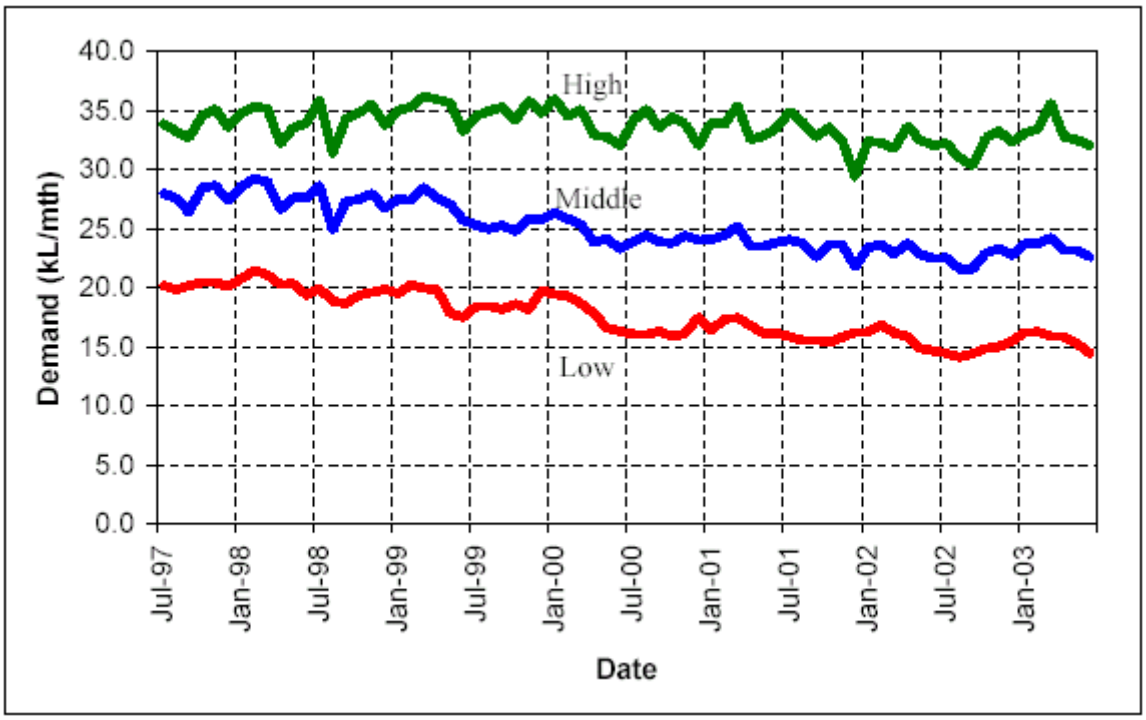

Figure 1. Graph indicating the change in monthly average household water consumption between 1997 and 2003 for low, middle and high income group samples.

Figure 1 shows 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.

A frequency distribution of the annual mean monthly demand was generated from the sample data. It is interesting to note the differences in frequency distribution between the three different income groups in 2002 / 2003 (Figure 2). The distribution for low income consumers is highly skewed to the left, while the distribution of high income consumers is more symmetrical. The frequency distribution and summary of mean and median demands (not included) 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.

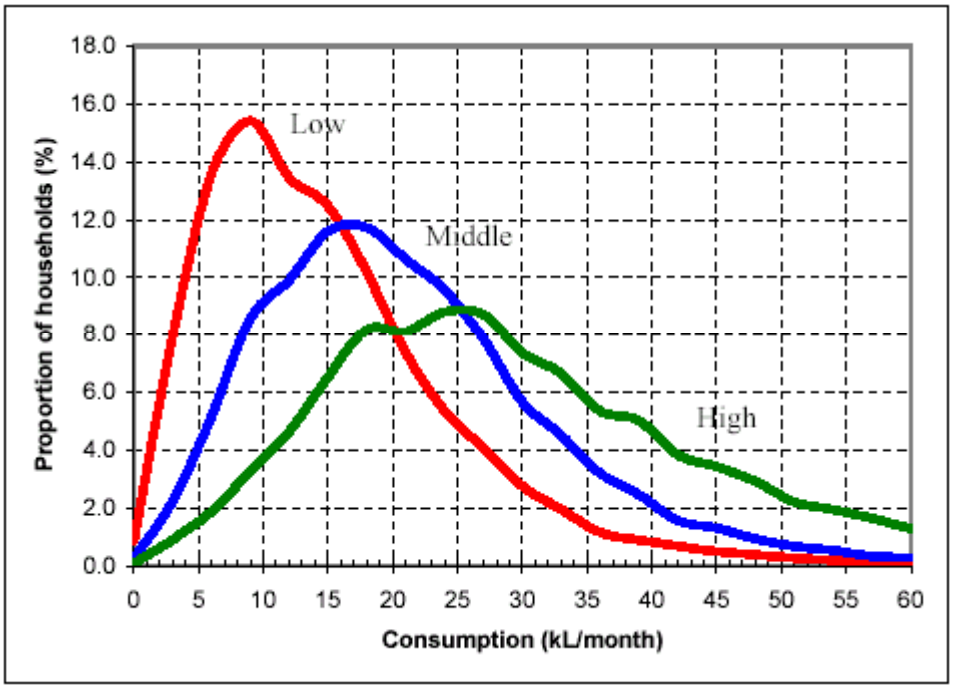

Figure 2. Frequency distribution of water consumption for all low, middle and high income groups in 2002/2003 (n ≈ 12 000).

During the study period the development of the increasing block tariff and the change in real prices between 1996 and 2003 is shown in Figure 3.

In Figure 4 the average monthly demand over a financial year (July to June) has been plotted against the corresponding 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 block (High 1) and the greater than 30 kL block (High 2). The mean consumption for high income households falls above the 30 kL mark but the median consumption falls below 30 kL. 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.

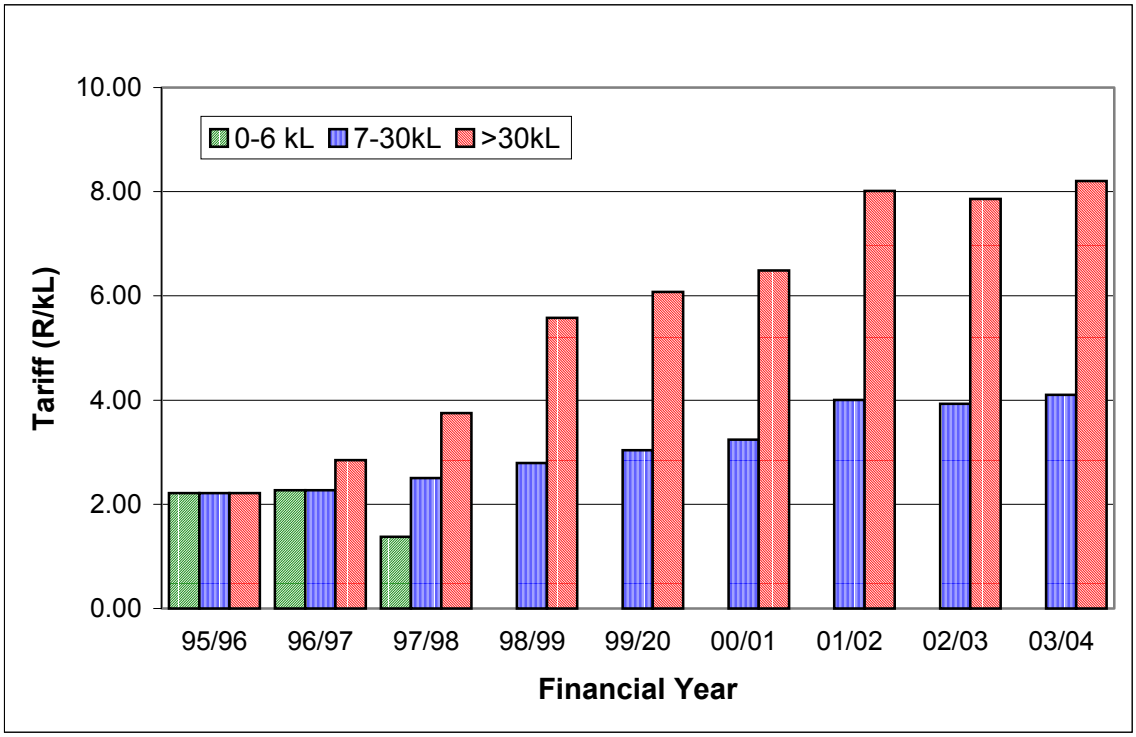

Figure 3. Change in real (base 2000) domestic water tariff between 1995 and 2003 showing the development of the increasing block tariff.

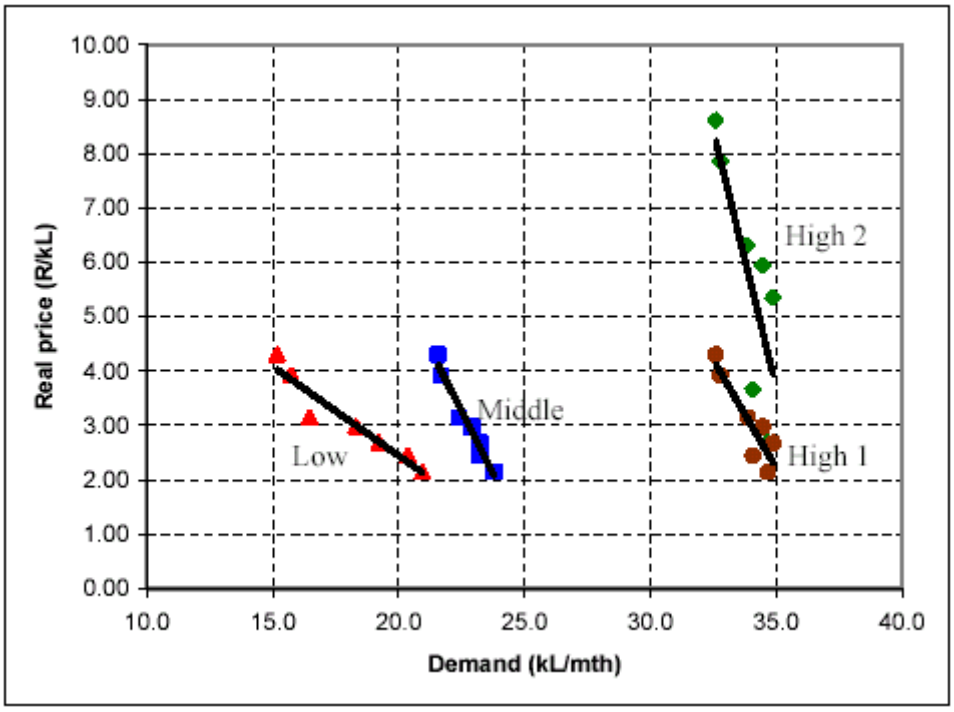

Figure 4. Relationship between average monthly demand and price for low, middle and high income groups.

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 price divided by the average demand The estimates of price elasticity found using the most significant regression models are summarised in Table 1 together with the applicable 95% confidence interval.

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.

Table 1. Estimated 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

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 costs were roughly assigned to fixed cost per consumer, fixed cost per kL, and 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.

The short run marginal cost of supply would be approximately equal to the variable costs of supplying an additional kL of water. 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.

APPLICATION OF RAMSEY PRICING

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.

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 stated at 27 kL/month. Fixed charges were levied at 6; 12; and 18 kL / 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/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; 15; and 21 kL /month.

The accumulated frequency distribution shown in Figure 5 guided the setting of these blocks and shows the spill over of other income groups using water in the targeted block.

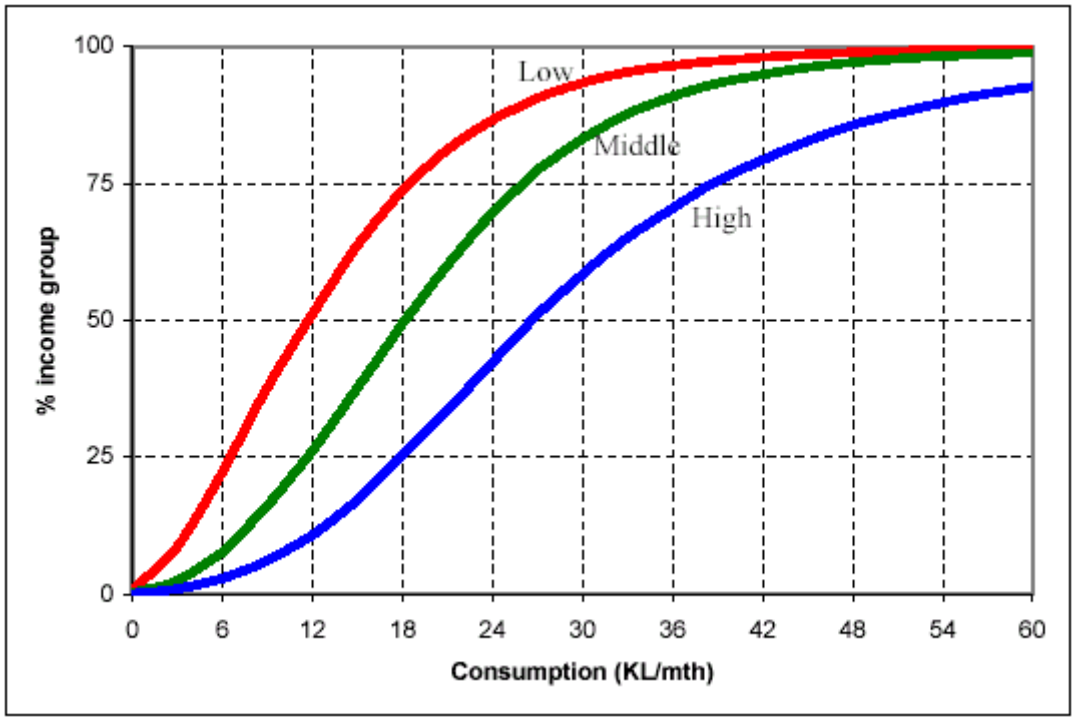

Figure 5. The accumulated frequency distribution of the low, middle and high income groups in 2002 / 2003.

Table 2 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 for that block, as well as a greater proportion of higher income households.

Table 2. Proposed block structures showing the proportion and accumulated proportion of consumers from the low, middle and high income households in each block.

	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**

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 study 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. 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.

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 earlier, 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 C1 = C2 = C3 = R 2.28.

From Table 1, 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 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 subsidising the access costs for lower income households

The calculated new tariff structures are presented with the old tariff structure in Table 3. Which 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 6. The fixed cost component of the service was based on a fixed cost of R 46.62 per connection plus R 1.08 per kL for a 30 kL/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 6 that all consumers who use less than 27 kL/month benefited from the new tariff structures. This represented 73% 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 6 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. 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

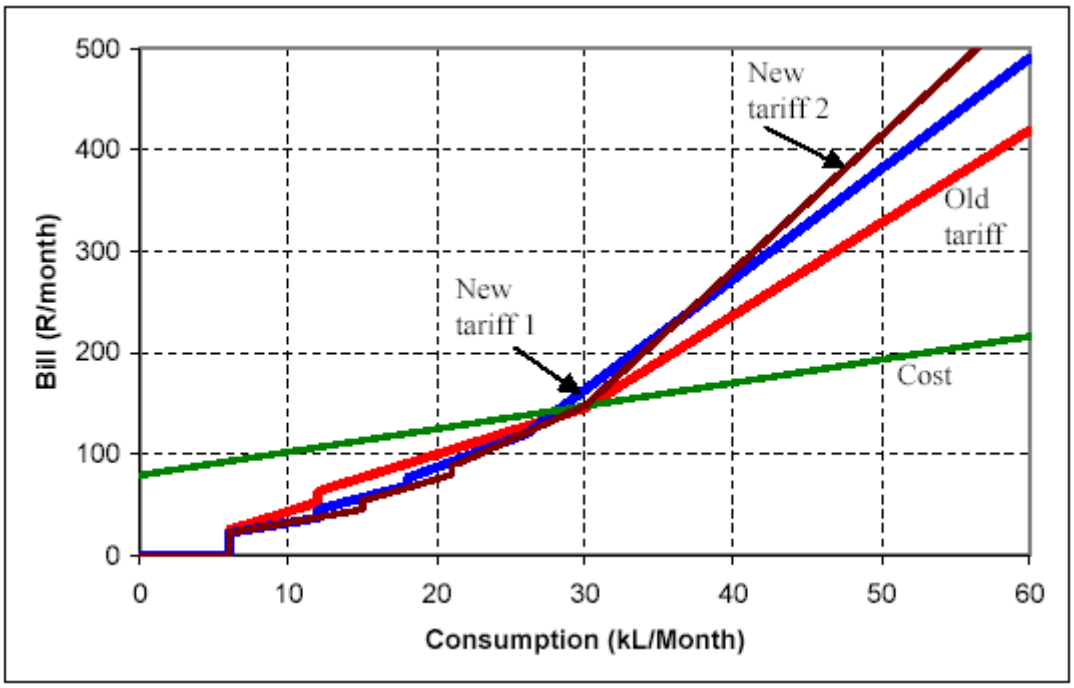

Figure 6. Graph showing the change in average bill using the new tariffs as against the old tariff.

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 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. This together with the old and new tariffs is presented graphically in Figure 7.

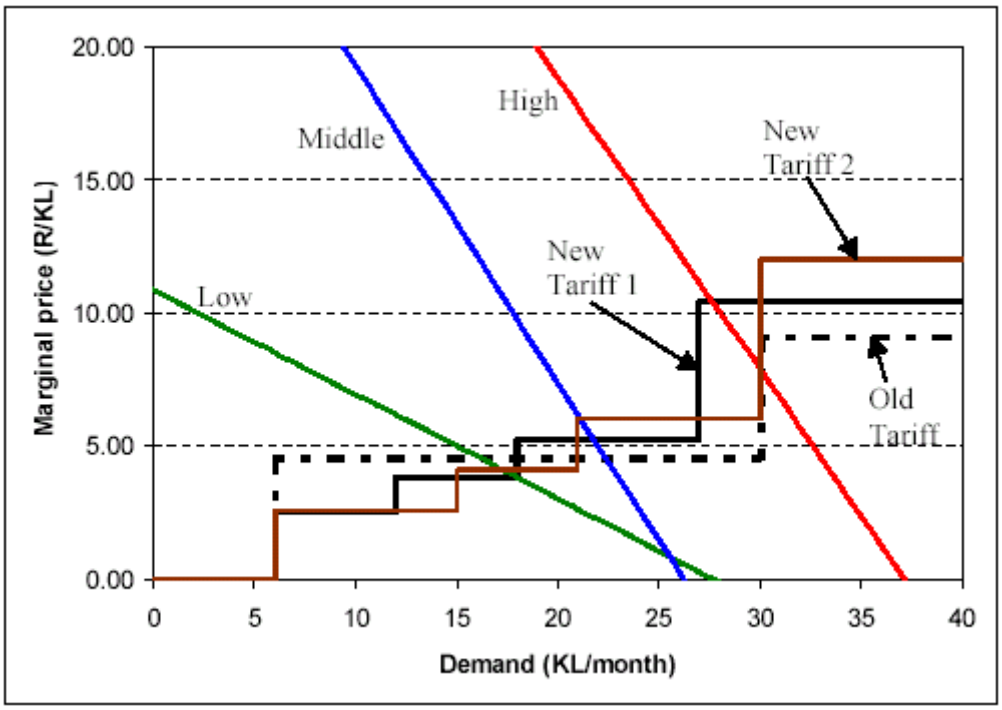

Figure 7. Consumer demand curves for low, middle and high income households plotted with the marginal price of water for the old and new tariffs.

Note that the consumer demand curve had only been estimated using linear regression for real (year 2000) prices between R 2.15 and R 4.31. 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 4.

A surprising but not unexpected observation is that all 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 5 shows the actual volumes of water sold in each consumption bracket per consumer group.

From Table 5 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 5 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.

Table 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%

Table 5. 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	8 454	8 850	8 937	26 241	6.2
6 > ≤ 15	21 741	29 457	33 375	84 573	20.0
15 > ≤ 21	11 976	21 819	30 531	64 326	15.2
21 > ≤ 30	10 758	24 507	46 077	81 342	19.3
30 >	8 400	27 285	130 332	166 017	**39.3**
Total	61 329	111 918	249 252	422 499	100.0
Total (%)	**14.5**	26.5	**59.0**	100.0	

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.

REFERENCES

1. StatsSA, Census 2001. *Statistics South Africa*. Available: http://www.statssa.gov.za/SpecialProjects/Census2001/Census/Database/Census%202001/Census%202001.asp [2003].
2. F. Ramsey, A Contribution to the Theory of Taxation. The Economic Journal, March, pg 47-61, England (1927).
3. D. Bös, Economic Theory of Public Enterprise. Lecture Notes in Economics and Mathematical Systems. Bonn, Springer-Verlag (1981).
4. W.R. Bailey, Designing a welfare maximising water tariff for Durban with Ramsey pricing principles, MBA in Water Management dissertation, University of Natal, Pietermaritzburg, South Africa (2003).