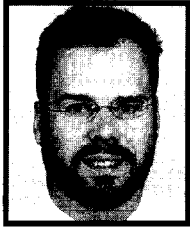


Potential application of end-use demand modelling in South Africa

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End-use water demand modelling is used to generate water demand projections by modelling various end uses, for example showers, toilets and washing machines. End-use models can be used to estimate water demand changes due to various scenarios, such as price increases, housing densification and conservation programmes. This study reports on the potential application of end-use modelling in South Africa, based on a pilot study that was done for Rand Water. The model includes elasticities of water demand with respect to variations in water price, household income, stand size and pressure. The study highlights many of the difficulties and limitations, as well as the potential applications of end-use modelling as a water demand predictor. A special effort is made to explain the meaning and application of elasticity in end-use modelling. Various data sources were used to determine elasticities for the variables used, and to identify minimum and maximum elasticity values. The implications of the elasticities are illustrated using a sensitivity analysis and case study.

INTRODUCTION

Water demand modelling is used by engineers to analyse and predict water consumption in cities and towns under varying conditions. In end-use modelling, the points of water consumption, for example showers, toilets and washing machines, are modelled individually or in groups. The characteristics of various water-using fixtures, the behaviour of users and the sensitivity of water demand to different parameters can be incorporated in a very detailed end-use model of water demand. Once an end-use model of a supply area is available, water demand can be predicted under hypothetical scenarios.

Rand Water commissioned a pilot study to demonstrate the strengths and weaknesses of end-use modelling as a water demand predictor for their supply area. The study included the entire residential sectors of Alberton, Boksburg, Centurion and Midrand, consisting of more than 110 000 stands. For the purpose of this pilot study, end uses were grouped into outdoor consumption, indoor consumption and leakage. The variables and elasticities in the model were limited to water price, household income, stand size and pressure. Data for the end-use model were obtained from numerous Rand Water consumer surveys, as well as published international and local research.

The study was not aimed at developing a comprehensive model of water demand in the study area, but limited to a pilot study to illustrate the difficulties and the potential application of end-use modelling as a water demand predictor. Various causative factors of water demand, such as temperature, rainfall, level of service and age of infrastructure were not considered. Although the study focused on a restricted number of variables in a specific geographical area, its results provide general pointers to the potential application of end-use modelling in South Africa.

The body of the paper starts with some background on end-use modelling, followed by a discussion on the construction of the end-use model, including the choice of modelling parameters and data collection. The results of a sensitivity analysis, in which each of the elasticity parameters was varied between minimum, normal and maximum expected values, are then discussed. Finally, a case study comprising the four areas included in the study (Alberton, Boksburg, Centurion and Midrand) is used to show some of the possible applications of end-use modelling in the Rand Water supply area.

DEFINITIONS OF ELASTICITY

A commonly used definition of elasticity is the relative change in demand if the given causative factor doubles. For example, if the water price increases by 100 % and the demand drops by 20 %, the elasticity would be $-0,20$. In mathematical terms:

$$\frac{\Delta D}{D} = E \left(\frac{\Delta F}{F} \right) \quad (1)$$

With Δ = a change
 F = a causative factor
 D = water demand
 E = a measure of elasticity

To determine the elasticity E , demand is plotted on a linear scale against the causative factor, with a smoothing or regression line to achieve continuity. By determining the slope of the line at a specific point, the elasticity E at that point can be determined:

$$E = \left(\frac{\Delta D}{\Delta F} \right) \left(\frac{F}{D} \right) \quad (2)$$

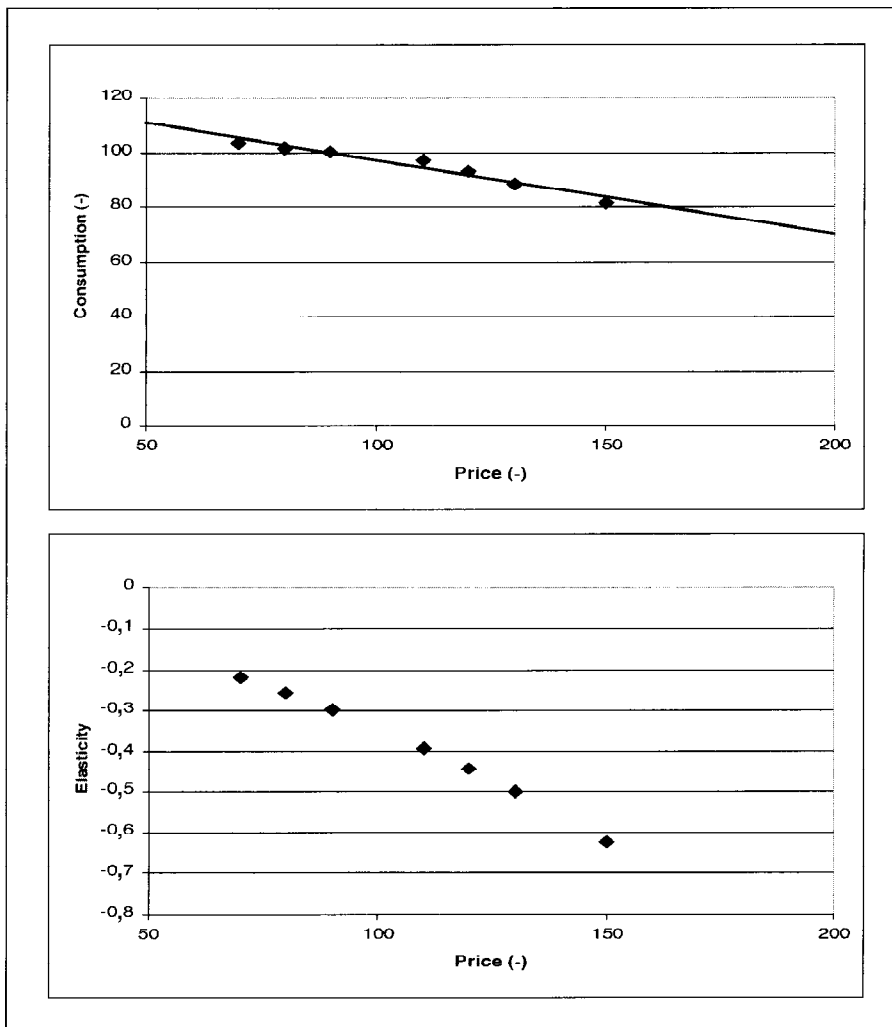


Figure 1 Elasticity values using the traditional approach (equation 2). The elasticity value (E) varies with water price. Data from Business Enterprises at University of Pretoria (2000)

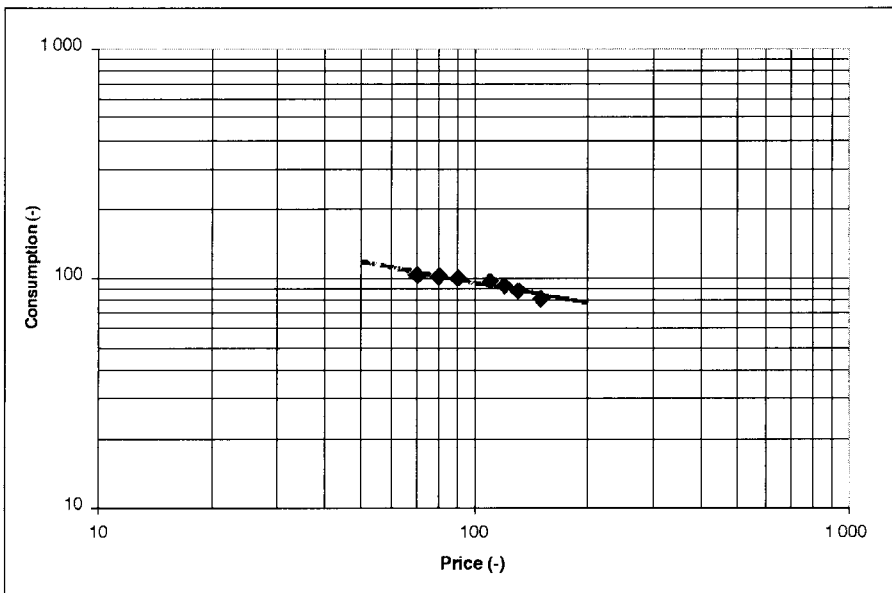


Figure 2 Elasticity value using the β approach (equation 3). The slope of the curve (-0,295) gives the value of β

By repeating this calculation for all the points on the curve, a second curve can be constructed, showing elasticity as a function of the causative factor. In a previous Rand Water study (Business Enterprises at University of Pretoria 2000), the elasticity of water demand with respect to

water price was determined in this way. The demand versus price (as obtained by consumer survey) was first obtained and the elasticity versus price was calculated next. An example from this study is shown in figure 1.

Although the above definition of elas-

ticity is the one commonly used by economists, it is not convenient for modelling. The elasticity E as defined above is not constant and is only meaningful at a specific value of the causative factor. An alternative expression of elasticity β can be formulated as:

$$\frac{D_2}{D_1} = \left(\frac{F_2}{F_1} \right)^\beta \quad (3)$$

With β = a measure of elasticity
 Subscript 1 = before a change
 Subscript 2 = after a change

To obtain β , the demand is plotted against the causative factor F on a log-log scale. The slope of the linear regression line will then be β . The same data shown in figure 1 are re-analysed in this way in figure 2, yielding a β -value of -0,295.

The advantage of the constancy of this measure of elasticity β is obvious, and β has therefore been adopted for use in this study.

The relationship between E and β

Although the elasticity definitions used for E and β (equations 1 and 3) are different, it is useful to explore the relationship between them mathematically in the region of the base point.

First, write equation 3 in terms of D and ΔD :

$$1 + \frac{\Delta D}{D} = \left(1 + \frac{\Delta F}{F} \right)^\beta \quad (4)$$

Then replace equation 1 into this equation:

$$1 + E \frac{\Delta F}{F} = \left(1 + \frac{\Delta F}{F} \right)^\beta \quad (5)$$

The variable β can now be written in terms of E by taking the natural logarithm on both sides of the equation and simplifying.

$$\beta = \frac{\ln \left(1 + E \frac{\Delta F}{F} \right)}{\ln \left(1 + \frac{\Delta F}{F} \right)} \quad (6)$$

Our interest is to find the relationship at the base point; in other words, where ΔF approaches zero. Expanding each natural logarithm as a Maclaurin series,

$$\ln(1+x) = x - \frac{x^2}{2!} + \frac{x^3}{3!} - \frac{x^4}{4!} + \dots$$

and then neglecting higher order terms (assuming small absolute elasticity values) further simplifies the equation to:

$$\beta = E \quad (7)$$

Table 1 Summary of published short-term price elasticities (adapted from Veck & Bill 2000)

Authors	Year	Location	Price elasticity		
			Indoor	Outdoor	Total
Carver and Boland	1969	Washington, DC	-	-	-0,1
Hanke and De Mare	1971	Malmö, Sweden	-	-	-0,15
Döckel	1973	Gauteng, South Africa	-	-	-0,69
Billings and Agthe	1974	Tucson, Arizona	-	-	-0,18
Martin <i>et al</i>	1976	Tucson, Arizona	-	-	-0,26
Gallagher <i>et al</i>	1972/3 & 1976/7	Toowoomba, Queensland	-	-	-0,26
Thomas and Syme	1979	Perth, Australia	-0,04	-0,31	-0,18
Boistard	1985	France	-	-	-0,17
Veck and Bill	2000	Alberton, South Africa	-0,13	-0,47	-0,18
		Thokoza, South Africa	-0,14	-0,19	-0,14
		Alberton and Thokoza, South Africa	-0,13	-0,38	-0,17
Rand Water study	2000	Alberton, South Africa	-0,24	-0,39	-0,29
		Thokoza, South Africa	-0,67	-0,79	-0,69

The result shows that β and E has the same value at the base point and that these values can be interchanged in calculations. However, care should be taken not to extrapolate calculations too far beyond the base point, unless the elasticity value is based on a range of data points to justify the greater range of application.

Working with unit consumptions

In some instances it is convenient to express demand as a consumption per unit of the causative factor, rather than per stand. For example, water demand is sometimes expressed in m³ consumption per square metre of stand area instead of m³ per stand. It is thus necessary to derive an expression for the relationship between the elasticity values based on per unit consumption and per stand consumption. Consider a unit consumption d , defined by

$$d = \frac{D}{F} \quad (8)$$

With D = water demand per stand
 F = the value of the causative factor per stand

The variation of unit consumption with causative factor F can be expressed as (from equation 3):

$$\frac{d_2}{d_1} = \left(\frac{F_2}{F_1} \right)^\alpha \quad (9)$$

With α = the elasticity based on unit consumption

Now, to convert elasticity based on unit consumption (α) to elasticity based on per-stand consumption (β), the fraction (D_2/D_1) is first written in terms of d and F :

$$\frac{D_2}{D_1} = \frac{d_2 F_2}{d_1 F_1} \quad (10)$$

Equation 9 is replaced into equation 10 and simplified to obtain:

$$\frac{D_2}{D_1} = \left(\frac{F_2}{F_1} \right)^{\alpha+1} \quad (11)$$

In other words, the relationship between elasticities based on D and d is given by:

$$\beta = \alpha + 1 \quad (12)$$

STRUCTURE OF THE WATER DEMAND MODEL

A water demand model incorporating water price, household income, stand size and pressure was used in this study. The model is expressed mathematically as:

$$AADD = AADD_{average} \left(\frac{T_2}{T_1} \right)^{\beta_T} \left(\frac{I_2}{I_1} \right)^{\beta_I} \left(\frac{A_2}{A_1} \right)^{\beta_A} \left(\frac{P_2}{P_1} \right)^{\beta_P} \quad (13)$$

With $AADD$ = annual average daily demand

- T = water price
- I = household income
- A = area or stand size
- P = water pressure

The most basic classification of domestic consumption is between indoor and outdoor consumption. The above model was thus applied separately to indoor and outdoor water demand. System leakage was included as a third demand type in the model.

To differentiate between different classes of consumers, Rand Water adopted a three-tier classification in its consumer surveys – informal settlements, townships and suburbs. Since it is very difficult to obtain reliable data for informal settlements, only suburbs and townships were included in this study.

Modelling was done using the software package IWR-Main (Planning and Management Consultants 1999). This package allows various different user types, elasticities and demand scenarios to be modelled simultaneously, making it a powerful modelling tool.

ELASTICITIES

In order to model the response of the water demand to various scenarios, the elasticity of water demand with respect to its causative factors must be known. In this study, four causative factors were analysed, namely water price, household income, stand size and water pressure. Elasticity values were estimated based on stand meter readings, thus excluding the effect of leakage in the municipal pipe networks.

Price elasticity

The price of water is arguably the most important determinant of water demand. It is also one of the easiest and cheapest for a water supply authority to implement. Metcalf published the first price elasticity values for water demand in 1926 (Wong 1972). How and Linaweaver (1967) presented the first detailed account of price elasticity for water demand.

Water consumption response to changes in price is reasonably simple to calculate when a single water tariff is used. However, the problem becomes more complex for more complicated tariff

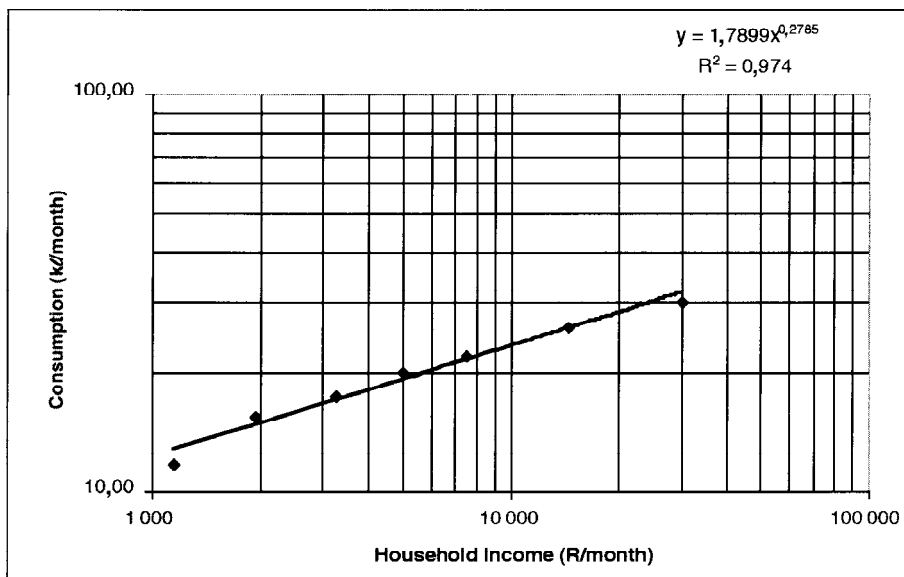


Figure 3 Income elasticities for suburbs

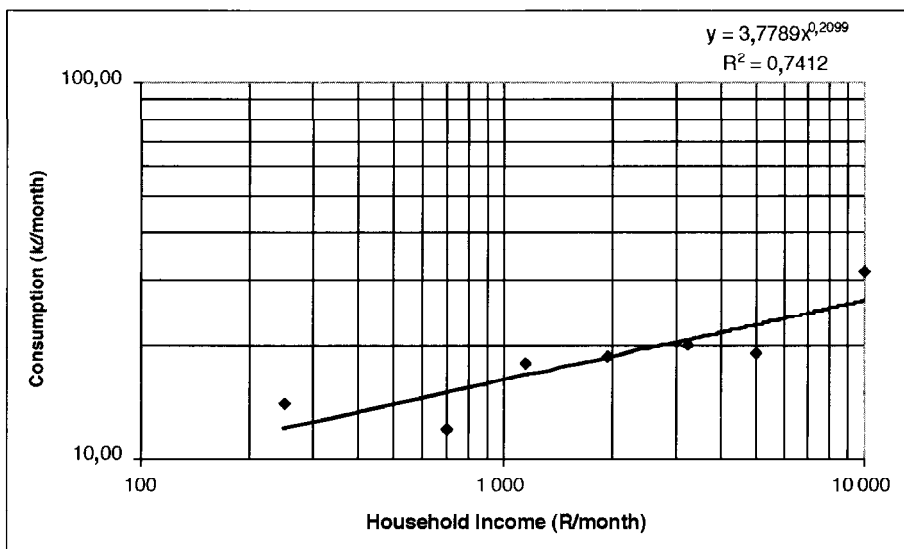


Figure 4 Income elasticities for townships

structures such as block rates. In such cases, the use of an average price would result in a loss of modelling accuracy (Billings & Agthe 1980). Block rates are normally handled using the marginal price and a difference value. The difference value typically represents the difference between a user's actual water bill and what would have been paid if the user's full consumption were charged at the marginal rate (Billings & Agthe 1980).

There are both upper and lower limits to the applicability of price as a water demand management tool. Water is necessary for life, and a certain minimum quantity of water will thus always be consumed, no matter what the price is. On the other hand, there is a physical limitation to the quantity of water that a user can obtain from the distribution system and thus will never exceed, even if water is free.

The price elasticity of water is normally higher for outdoor use than for indoor use because the outdoor consumption is typically less critical to the user. An important factor here is the fraction of the total water consumption that is used outdoors. Areas with small stands

and no garden irrigation would typically have a smaller fraction of outdoor use, thus increasing the significance of the indoor price elasticity values.

Price elasticity changes with time and it is possible to differentiate between short-term and long-term elasticities. Price increases will have an immediate (short-term) effect by changing consumers' water use patterns, but will have little immediate effect on house fixtures. However, in the longer term, the increased cost of water stimulates the installation of water saving fixtures, resulting in higher elasticity values. Veck and Bill (2000) found from literature that the average short-term price elasticity is $-0,21$, while the average long-term price elasticity is $-0,6$. This gives some indication of how much more price increases can affect water consumption in the long term than in the short term.

A number of international and local studies on short-term price elasticity have been identified in the literature. A summary of the results of these studies is given in table 1. Three South African studies are included: Veck and Bill (2000) conducted a study on price elasticity by

means of a contingent valuation approach. In this approach, a survey of water users is done in which they are asked to indicate how they would adjust their water consumption if the price of water is increased or decreased by certain quantities. The results of this type of study are not as reliable as actual measured responses, but unfortunately there is very little good data available. Veck and Bill studied different income groups in Alberton and Thokoza and determined indoor and outdoor price elasticity values of $-0,13$ and $-0,47$ respectively for Alberton, and $-0,14$ and $-0,19$ respectively for Thokoza.

In the second South African study, Döckel (1973) also used a contingent valuation approach to study price elasticity in Gauteng. He found a price elasticity value of $-0,69$.

A third South African price elasticity study was done by a commercial company for Rand Water (Business Enterprises at University of Pretoria 2000). The study was done in the Alberton and Thokoza areas, also using a contingent valuation approach. This study provided much more detailed data values for price elasticity and could be used to fit a β elasticity value over a range of data points, instead of basing it on a single data point. The study only determined overall elasticity values. To differentiate between indoor and outdoor consumption, average outdoor consumptions of 40 % and 15 % respectively were assumed for suburbs and townships.

Income elasticity

Quality data on income elasticity of water use are scarcer than data on price elasticity. Fortunately, Rand Water did a detailed survey (MSSA 2001) on water consumption behaviour in its supply area, providing a good basis for estimating elasticity values. No logical differentiation could be made in this case between indoor and outdoor elasticities.

The survey data had to be sieved to obtain relevant elasticity values: the data were first categorised according to town type (eg suburbs and townships). All non-residential users and estates (townhouses, clusters, etc) were removed from the data set to ensure that the elasticities reflect only normal housing units. Data points in which the demand was estimated by the user (rather than obtained from actual meter readings) were also eliminated from the data set. The remaining data were then analysed to obtain income elasticity values.

The data used to calculate income elasticities are shown in figures 3 and 4 for suburbs and townships respectively. The resulting elasticity values (β) are 0,28 for suburbs and 0,21 for townships.

Area elasticity

Data for the investigation of area or stand size elasticity were extracted from Trea-

Table 2 Distribution of stands used in the stand size elasticity analysis

Stand value category (R/m ²)	Alberton		Boksburg		Centurion		Midrand	
	No of stands	Ave AADD (l/m ²)	No of stands	Ave AADD (l/m ²)	No of stands	Ave AADD (l/m ²)	No of stands	Ave AADD (l/m ²)
10–30	16 168	1,76	8 956	1,81	1 706	0,95	2 890	1,55
30–50	13 219	1,33	20 351	2,10	13 090	1,23	7 537	1,48
50–70	1 245	1,23	10 040	1,82	5 964	1,67	2 646	1,14
70–150	538	1,40	4 584	1,36	1 258	1,67	2 967	1,69
Total	3 1170		43 931		22 018		16 040	

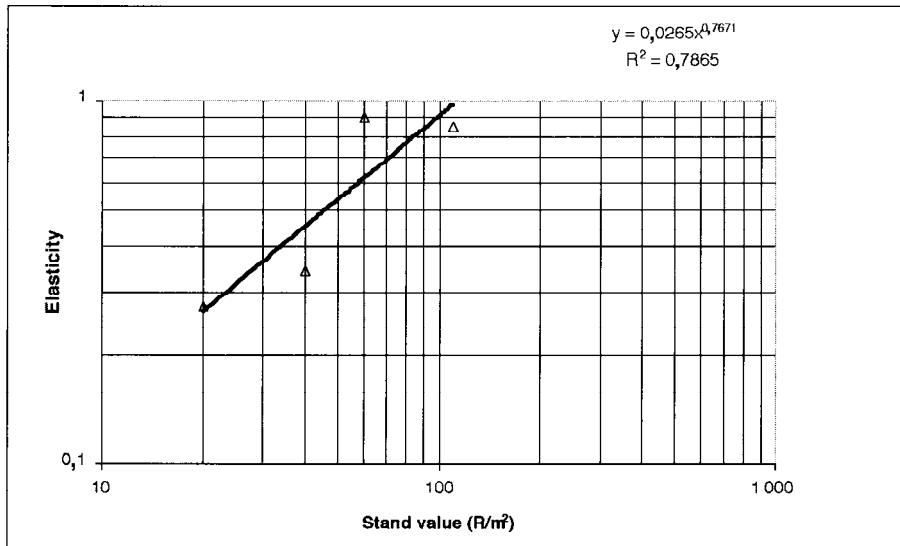


Figure 5 Summary of average outdoor elasticities based on unit consumption for different stand value categories

Table 3 Final elasticity parameters used in the sensitivity analysis

Description		Suburbs		Townships	
		Inside	Outside	Inside	Outside
Fraction of consumption		50 %	50 %	80 %	20 %
β price (short-term)	Min abs	-0,05	-0,30	-0,00	-0,20
	Norm	-0,20	-0,40	-0,30	-0,50
	Max abs.	-0,30	-0,50	-0,70	-0,80
β price (long-term)	Min abs	-0,10	-0,60	-0,00	-0,40
	Norm	-0,40	-0,80	-0,60	-1,00
	Max abs	-0,60	-1,0	-1,40	-1,60
β income	Min abs	0,20		0,10	
	Norm	0,28		0,21	
	Max abs	0,35		0,40	
β stand size	Min abs	0	1,2	0	1,2
	Norm	0	1,6	0	1,28
	Max abs	0	2,3	0	1,4
β pressure	Min abs	0,15		0,10	
	Norm	0,20		0,15	
	Max abs	0,25		0,20	

Note: Minimum and maximum values relate to the absolute of the elasticity values.

surey databases using the SWIFT (Sewer & Water Interface to Treasury) software package. Data for more than 110 000

domestic users in Alberton, Boksburg, Centurion and Midrand were included in the analysis.

To ensure that the data used in the analysis were of good quality, a number of filters were used to exclude suspect data points. The first filter excluded users with a stand AADD below 0,1 kl/d and above 30 kl/d. The second filter excluded users with a stand size smaller than 200 m² and larger than 2 000 m². A final filter excluded stands with a value (using municipal valuations) below R10/m² and above R150/m².

The data were grouped according to municipal valuations. Four stand value categories were used, as shown in table 2. The number of stands and average AADD for each category are also given in the table.

A strong link exists between stand size and outdoor consumption. Larger stands would typically have larger gardens and thus require more water for outdoor use. Within the same stand value category, it may reasonably be assumed that the effect of stand size on indoor consumption is negligible, that is, have elasticities of zero. To separate indoor and outdoor consumption figures it was subsequently assumed that the smallest stands in suburbs and townships have outdoor consumptions of 10 % and 0 % of their total consumption respectively. Increases in consumption with increasing stand size were then assigned to outdoor consumption. The R10–R30/m² value category was taken as representative of townships and the R50–R70/m² value category as representative of suburbs.

A summary of the outdoor unit consumption elasticities calculated for the different stand value categories is shown in figure 5. To obtain the elasticities for total consumption, the unit consumption elasticities should be increased by 1 (see equation 12).

Pressure elasticity

Pressure affects the flow rate through an opening in a pipe, and thus the leakage rate in a water distribution system. The theoretical relationship between pressure and flow rate dictates that the flow rate should be proportional to the square root of the pressure (hence a β elasticity value of 0,5). However, experience in actual systems indicates much higher values for β,

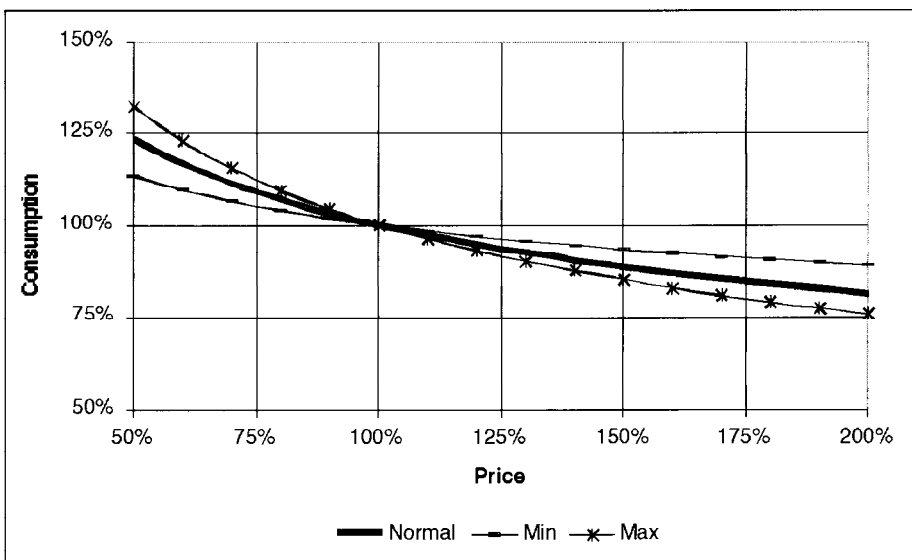


Figure 6 The short-term effect of changes in water price on consumption in suburbs

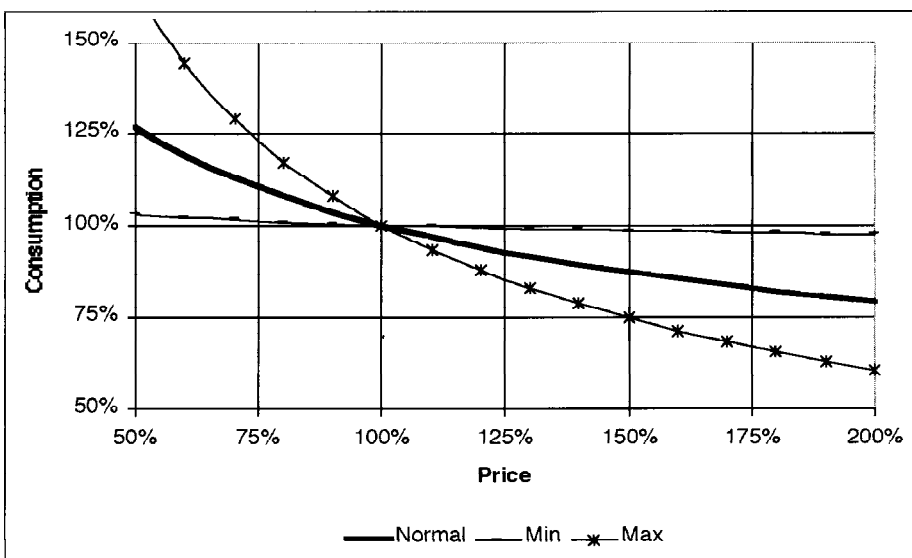


Figure 7 The short-term effect of changes in water price on consumption in townships

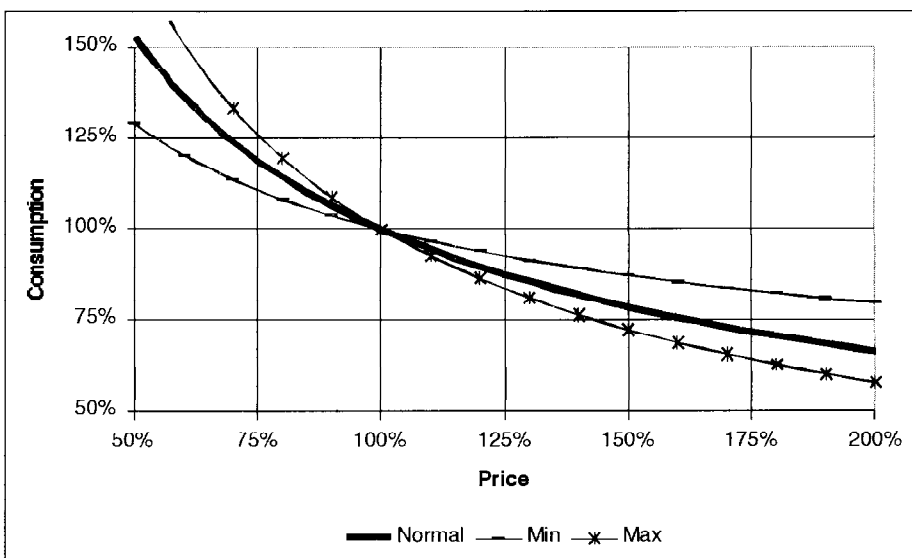


Figure 8 The long-term effect of changes in water price on consumption in suburbs

possibly because of the fact that the cross-sectional areas of some types of leaks are not fixed, but expand with increasing pressure. A default β value of 1 is often used for water loss estimation where

measured data are not available (McKenzie 2001).

Pressure can be expected to have an effect on non-leakage consumption too, especially when the consumption is not

measured in terms of volume (eg a bath or toilet cistern), but in terms of time. Wasteful water consumption (such as taps being left open for unnecessary long periods) was assumed to have the theoretical β value of 0,5. Since irrigation consumption can be controlled by time or volume, the elasticity value will typically vary between 0,5 and 0. Taking all these factors into account, the elasticity of household consumption was assumed to vary between 0,15 and 0,25.

SENSITIVITY ANALYSIS

Typical elasticity values for the causative parameters water price, household income, stand size and pressure were estimated based on the literature review and data analyses. Probable minimum and maximum elasticity values were also estimated. These values are given in table 3.

The numerical values of the elasticities in table 3 indicate which variables will have the greatest effect on water demand. Increasing the price of water will, for instance, have the greatest long-term effect on outside use in townships. However, this does not necessarily translate into the largest total saving of water, since townships typically only use a small fraction of their consumption outdoors.

To get the full picture, it is necessary to consider how the consumption is distributed between indoor and outdoor use and what fraction of the total use falls in the category under consideration. For the purpose of the study, suburbs were assumed to use 50 % of their consumption outdoors, and townships 20 %.

A sensitivity analysis was performed by plotting the consumption response to normal, minimum and maximum values for each parameter, as given in table 3. Only one parameter was changed at a time.

Price elasticity

Both long-term and short-term price elasticity values were considered in the sensitivity analysis. Short-term price elasticity reflects the immediate change in consumption behaviour of consumers due to a change in the water price, while long-term price elasticity also includes longer-term effects such as the introduction of water-saving fixtures in homes. Veck and Bill (2000) noted that long-term price elasticities can be three times higher than short-term price elasticities. In this study, long-term price elasticities were conservatively estimated to be twice that of the corresponding short-term elasticities.

The projected short-term changes in consumption due to changes in the water price are shown in figures 6 and 7 for suburbs and townships respectively. The graphs show that a 50 % increase in water price will result in consumption reducing by between 7 % and 15 % for suburbs, and between 2 % and 25 % for townships in the short term. The larger

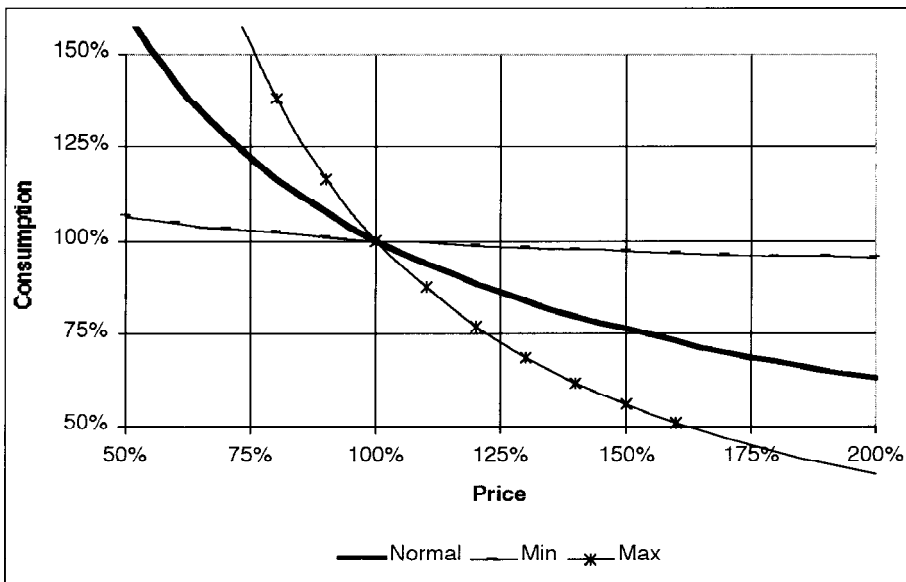


Figure 9 The long-term effect of changes in water price on consumption in townships

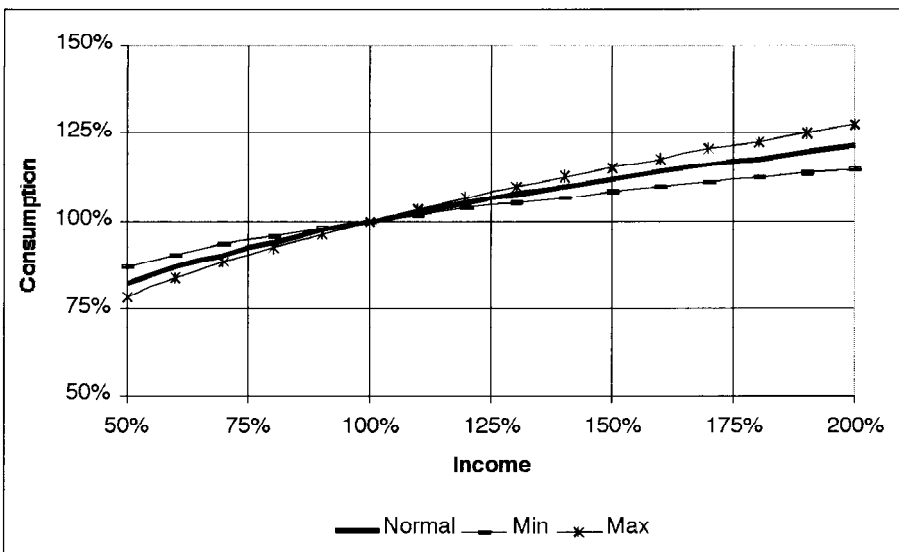


Figure 10 The effect of changes in income on consumption in suburbs

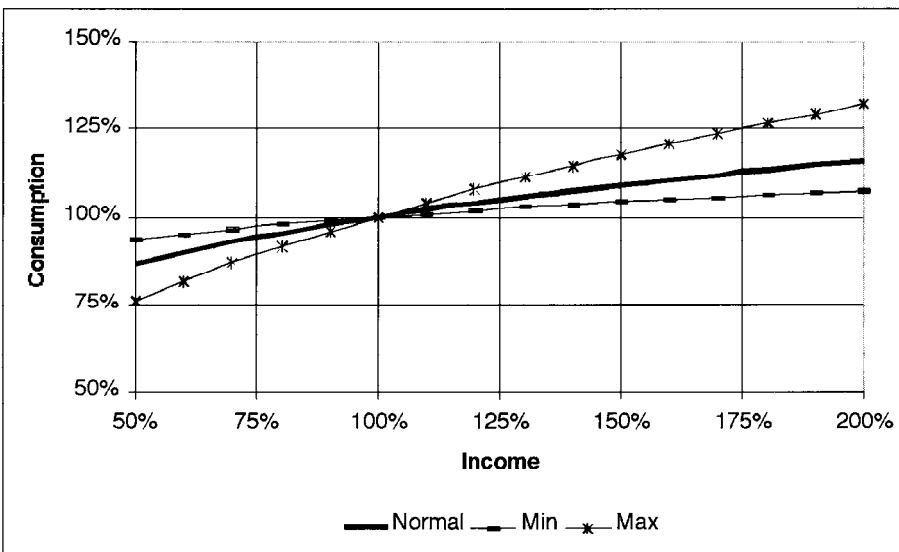


Figure 11 The effect of changes in income on consumption in townships

variation in the response of townships to price increases can be explained by considering two factors. First, people in townships are generally poorer and will thus be influenced more by water price

increases. Second, many people in townships already use little water and will not be able to reduce their consumption by much, even if the water price increases.

The results for townships are compli-

cated by two further factors, namely the problem of non-payment and the free basic water policy of government. It can be expected that users not paying for water will also not adjust their consumption to changes in the price of water. Price increases may, in some cases, have the opposite effect by increasing the rate of non-payment as a form of protest against the price increase.

The projected long-term changes in consumption due to changes in the water price follow the same pattern as that for short-term changes, but with larger effects on the final water consumption. The long-term price elasticity curves are shown in figures 8 and 9 for suburbs and townships respectively. The graphs show that a 50% increase in water price will result in consumption reducing by between 13% and 27% for suburbs, and between 3% and 44% for townships in the long term.

An interesting result is that local authorities will not only reduce consumption by increasing the price of water, but will also increase their income from water sales. In the suburbs example above, for instance, the local authority will increase their income from water sales by between 28% and 40% in the short term, and between 10% and 30% in the long term.

Income elasticity

The estimated changes in consumption due to changes in household income are shown in figures 10 and 11 for suburbs and townships respectively. The graphs show that a 20% increase in real income will result in consumption increasing by between 4% and 7% for suburbs, and between 2% and 8% for townships. The effect of income on water consumption is clearly much smaller than that of price. A factor that should be taken into consideration when interpreting the income elasticity graphs is that large changes in income would probably result in people moving out of a given area either to poorer or more affluent areas. Changes in income in specific areas should thus be limited to what can realistically be expected to occur within a given area.

Area elasticity

The estimated changes in consumption due to changes in the stand size are shown in figures 12 and 13 for suburbs and townships respectively. The graphs show that a 50% reduction in stand size (eg when stands are sub-divided) will result in per-stand consumption decreasing by between 28% and 40% for suburbs, and about 12% for townships. The sub-division will have the effect of doubling the number of stands, thus resulting in a nett increase in consumption by between 20% and 44% for suburbs, and by 76% for townships.

Since it has been assumed that indoor consumption is not affected by stand size, the nett effect of a change in stand size is

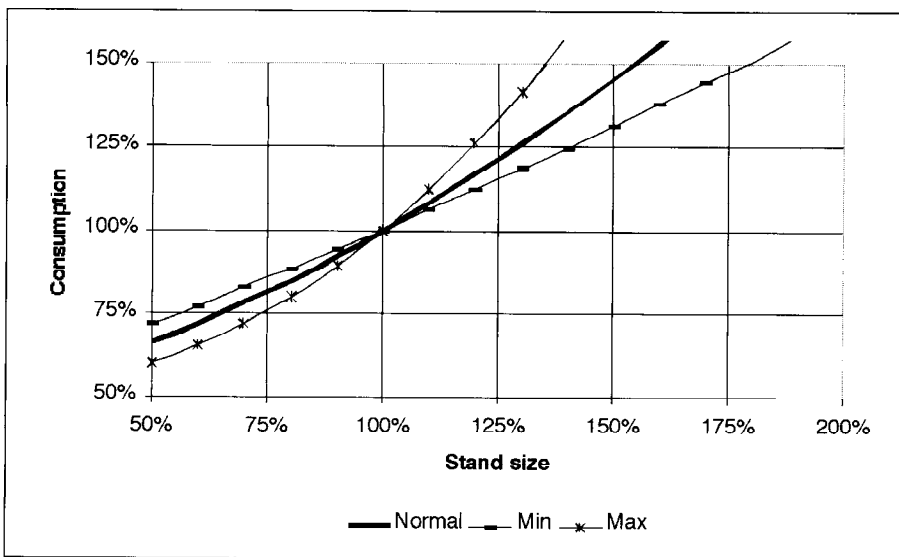


Figure 12 The effect of changes in stand size on per-stand consumption in suburbs

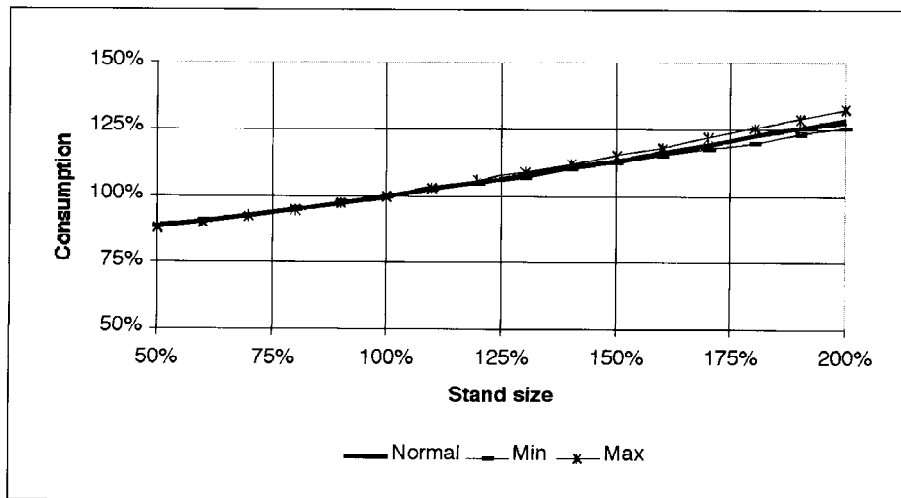


Figure 13 The effect of changes in stand size on per-stand consumption in townships

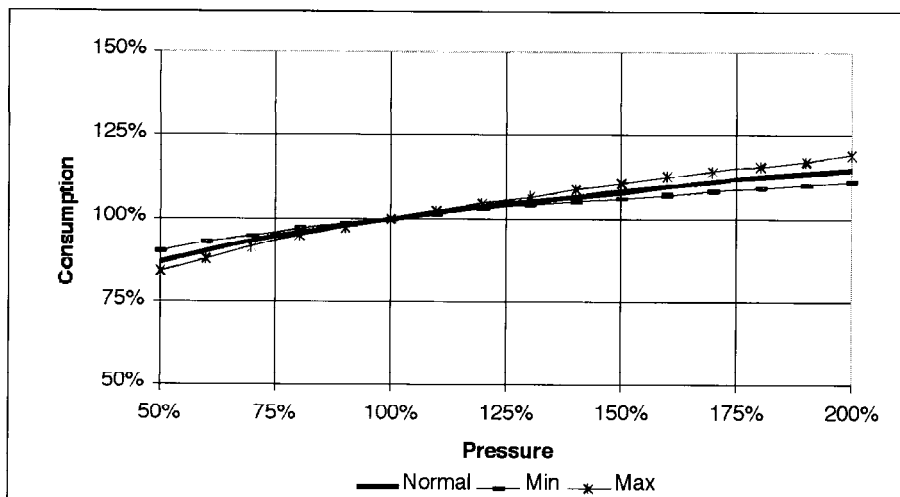


Figure 14 The effect of changes in pressure on consumption in suburbs (excludes the effect of pressure on losses)

a function of the outdoor elasticities (which are high for both suburbs and townships) and the fraction of consumption that is used outdoors. In townships this figure is generally low (20 % was assumed in the sensitivity analysis) resulting in a relatively small reduction because of subdivision of stands. Densification in townships, even if it is not by formal sub-

division, will thus have a much greater effect on the total water consumption than the same factor of densification in suburbs.

Pressure elasticity

Pressure affects certain aspects of water demand in which time is generally used

as a measure instead of volume (eg irrigation). The pressure elasticities in this study were based on the estimated effect on actual consumption and specifically exclude losses in the system. As a result, the estimated pressure elasticity values are much lower than those normally used in pressure management studies.

The estimated changes in consumption due to changes in pressure are shown in figures 14 and 15 for suburbs and townships respectively. The graphs show that a 50 % reduction in pressure will result in consumption decreasing by between 10 % and 16 % for suburbs, and between 7 % and 13 % for townships. The effect of pressure reduction on demand is thus expected to be small, although the main benefit of pressure control will be in the area of leakage reduction.

CASE STUDY

The sensitivity analysis gives an indication of how much water demand would be affected by changing a single parameter at a time. However, it does not provide information on the cumulative effect of different parameters changing simultaneously. Modelling real life scenarios requires the use of a software package, such as IWR-Main (Planning and Management Consultants 1999), to handle the complexities of the model.

End-use software packages allow the user to model very detailed end-use behaviour. Typical behaviour of individual components, such as toilets, baths and dishwashers, can be included in the model, each with their own elasticity values. In this pilot study, demand was grouped according to user category (suburbs and townships), type of demand (indoor and outdoor), and losses. Losses were modelled as a separate user with a pressure elasticity value of 1,0. This grouping is adequate to illustrate the mechanisms and capabilities of end-use modelling without getting caught up in unnecessary detail.

The IWR-Main end-use model covers the residential areas of Alberton, Boksburg, Centurion and Midrand. A general layout map of the areas is shown in figure 16. The area considered includes two township areas, namely Thokoza in Alberton and Vosloorus in Boksburg. The GIS maps for the areas showed that the R10-R30/m² stand value category in Alberton falls mainly in Thokoza. Similarly, the R10-R30 and R30-R50/m² categories in Boksburg falls mainly in Vosloorus. These categories were subsequently modelled as township areas in the IWR-Main model. The basic data used for suburbs and townships in the IWR-Main model are given in table 4.

It was assumed that suburbs have 50 % of their consumption outdoors, and townships 20 %. Losses were assumed to be 20 % of consumption for suburbs and 40 % for townships.

To show how end-use modelling can be employed to model future water

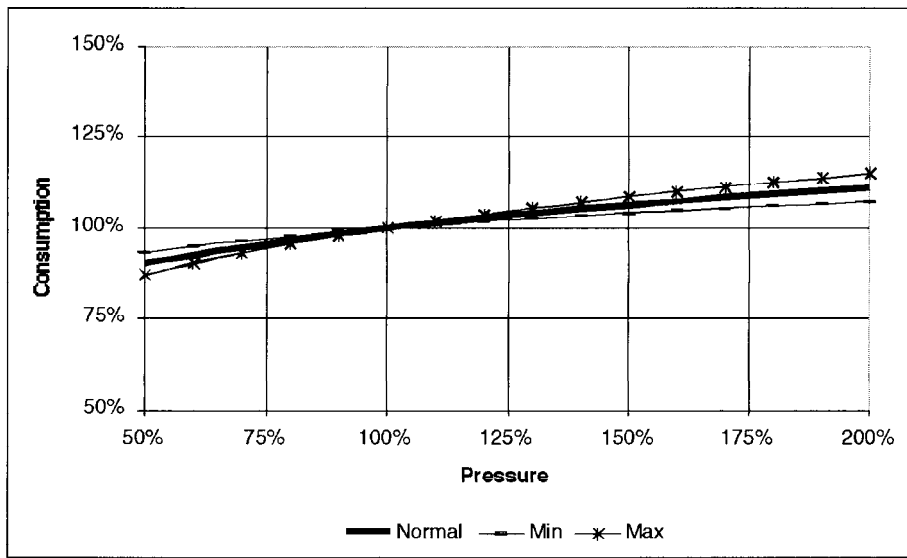


Figure 15 The effect of changes in pressure on consumption in townships (excludes the effect of pressure on losses)

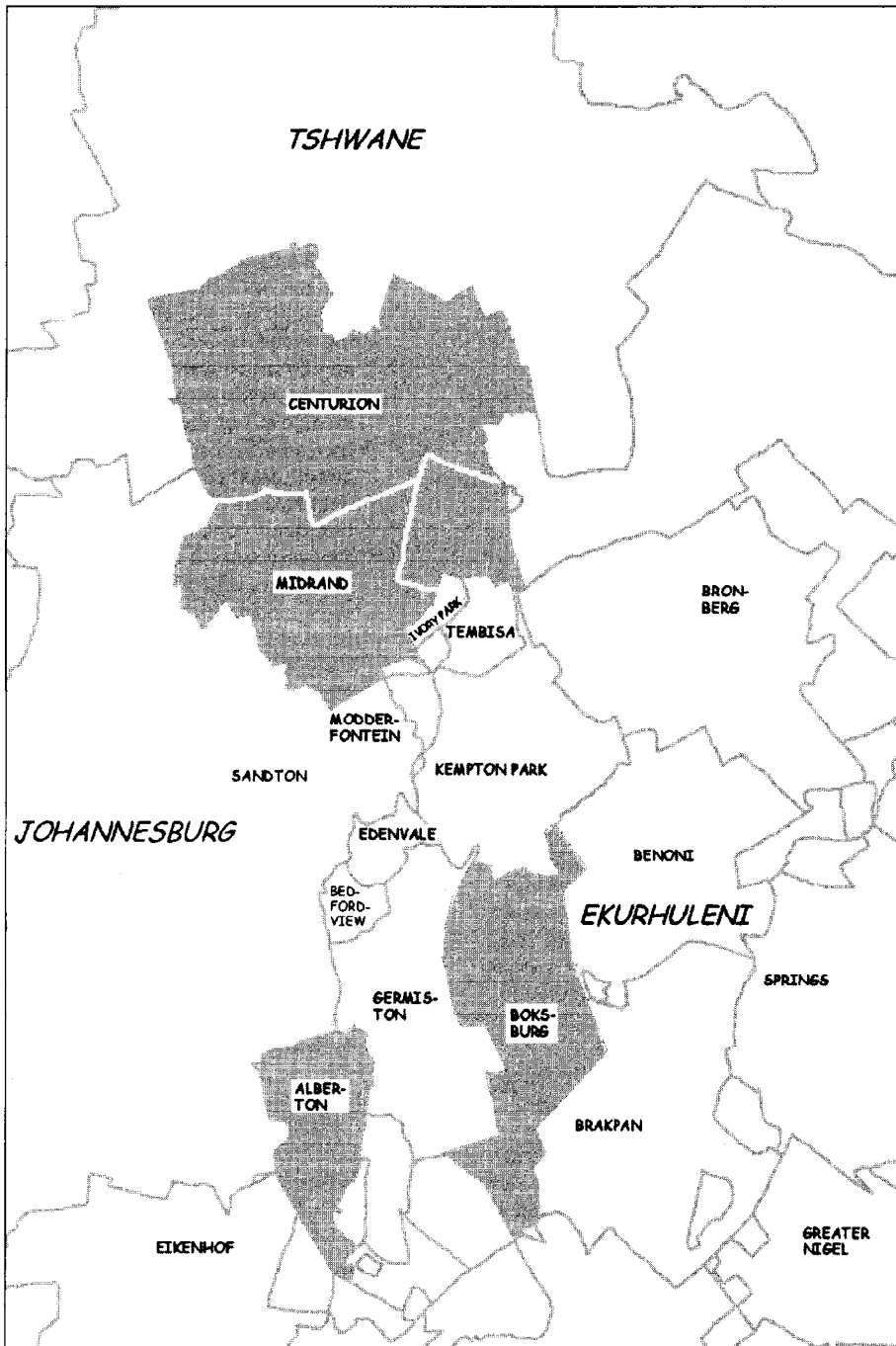


Figure 16 Layout of the study area

demand, a hypothetical scenario was compiled. The scenario consisted of the following:

- A projected real increase in household income of 1,5 % per annum for both suburbs and townships.
- A rate of densification of 0,5 % per annum for suburbs and 2,0 % per annum for townships.
- An immediate programme to reduce the pressure in both suburbs and townships by 10 % per annum for three years.
- A planned increase in the water price of 10 % per annum for suburbs and 5 % per annum for townships. The price increases will start in 2007 and will be implemented over a period of five years.

The projected consumption of the study area was calculated for a design horizon of ten years. To obtain an envelope of minimum and maximum values, combinations of elasticities were selected from table 3 for the various parameters to either maximise or minimise the total demand. For maximum demand, the minimum price, stand size and pressures elasticities, and the maximum income elasticity value were used. Conversely, for minimum demand, the maximum price, stand size and pressure elasticities, and the minimum income elasticity value were used. The results of the simulation are shown in figure 17.

The figure shows the cumulative effect of the various factors included in the scenario. A number of these factors will increase demand, namely the increases in income and housing density. Factors that will decrease the demand are decreases in system pressure, stand size and increases in the water price. The reduction in system pressure takes place in the first three years and is responsible for the initial reduction in demand. Most of this reduction is due to a reduction in leakage.

The second reduction in demand is caused by the increases in water price from 2007 to 2011. In years where none of the reducing factors were active (2006 and 2012), the demand shows a steady increase. Both factors decreasing demand can only be implemented up to a certain level, after which they will not be viable. Under the assumed conditions, demand would thus continue to increase in the long term, unless more permanent water demand measures can be enforced.

The minimum and maximum water demand curves in figure 17 are the theoretical envelope based on the elasticities used in the sensitivity analysis. It is highly unlikely that all the elasticities would vary from their normal values in such a way that one of these extreme curves will occur in practice. The actual demand curve can realistically be expected to be much closer to the expected value curve.

A potential source of modelling errors in the case study is possible interdepend-

Table 4 Basic data used in the IWR-Main model

Item	Suburbs	Townships	Total
Number of stands	67 684	45 475	113 159
Total daily consumption (kℓ)	74 882	36 047	110 929
Daily consumption per stand (ℓ)	1 106	793	-
Fraction of outdoor consumption assumed	50 %	20 %	-
Fraction losses assumed	20 %	40 %	-
Total daily losses (kℓ)	14 976	14 419	29 395

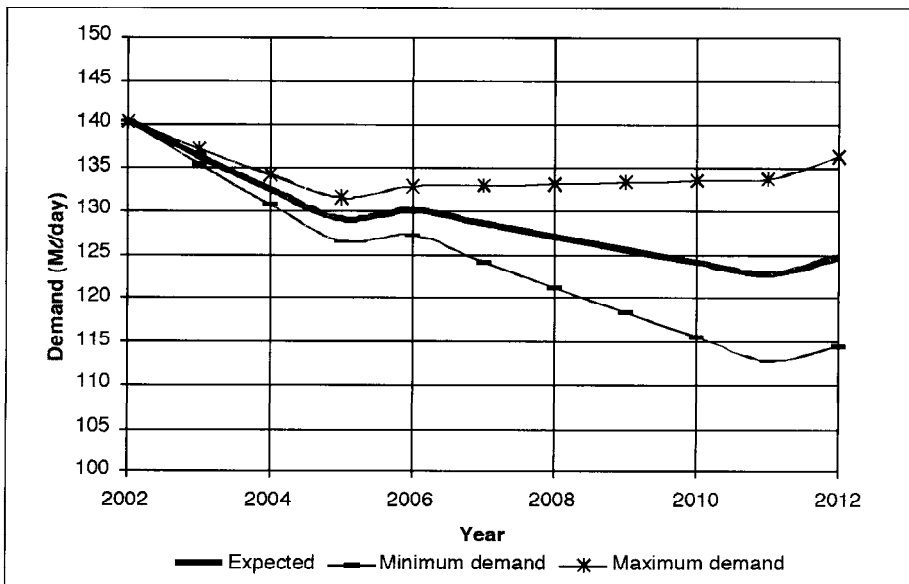


Figure 17 The projected future water demand for the study area

ence between modelling variables. A relationship may, for instance, exist between stand size and household income. To apply the water demand model to a real life system with increased accuracy, it is thus necessary to calibrate the model using measured data. Consequently, developing a water demand model should not be seen as a once-off exercise, but as a continuous project requiring frequent updating and refinement.

The case study shows how powerful end-use modelling can be in making predictions of water demand. Various possible scenarios can be identified and modelled to identify the most critical ones. Other factors can also be included in the model, such as

- the implementation over time of plumbing codes to install water saving fittings in houses
- including seasonal variations in demand to estimate minimum and maximum demands during each modelling year
- various active and passive conservation scenarios
- emergency conservation
- cost-benefit analyses of various programmes

Finally, it is important to stress that modelling results are dependent on the quali-

ty of the input data. It is thus imperative to understand the area being modelled and collect accurate and representative data for modelling purposes.

CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to demonstrate the strengths and weaknesses of end-use modelling as a water demand predictor for the Rand Water supply area. The study focused on four areas, namely Alberton, Boksburg, Centurion and Midrand. Data were collected from various Rand Water consumer surveys and studies, local and international literature and from Treasury databases via the SWIFT interface to Treasury databases of the study area. A special effort was also made to understand and explain the meaning and application of elasticity in end-use modelling.

The data were used to identify ranges of elasticity values for the modelling parameters selected, which were water price, household income, stand size and pressure. The effect of these elasticity values on water demand was illustrated in a sensitivity analysis, which highlighted the following factors:

- Elasticities for indoor and outdoor use differ for various parameters. The nett effect of changes in these

parameters not only depends on the elasticity values, but also on the quantities of indoor and outdoor consumption.

- When designing water demand management measures, the total demand of a given user group should be taken into consideration, and not only the effect that changes in parameters will have on the demand. A large reduction in the use of a group with a relatively small consumption will not reduce the total consumption by much.
- On a purely technical level, an increase in the price of water can be a good method for reducing water consumption. Not only does it have a large effect on demand, with the effect increasing in the long term, but the nett income of the local authority also increases. However, price may not be a good water demand measure in townships where price increases may increase the number of non-paying customers and where the effect of non-payment and the new free basic water will impact on the actual water savings made in a way that is difficult to estimate. There may also be significant political pressures against increasing the price of water.
- Income has a significant effect on consumption, but may not affect the overall consumption of a given area by much due to movement of people with increasing or decreasing income out of the area.
- Increase in consumption due to densification of suburban areas is tempered by the reduced consumption due to smaller stand sizes. However, since township areas generally have only a small fraction of their consumption outdoors, densification in townships can substantially increase the water demand of these areas.
- Pressure management has a small, but significant effect on consumption. However, the main benefit of pressure management will remain as a measure to decrease water losses due to leakage in the system.
- It is necessary to view a water demand model as a continuous project, with increased accuracy gained over time through frequent updating and refining of the model, and using measured data to calibrate the model variables.

Although the sensitivity analysis was useful in highlighting certain important aspects of individual model parameters, it cannot be used to estimate the combined effects of different areas, user types and parameters. Software packages are typically employed for this purpose. A case study with arbitrarily selected parameters was used to illustrate the way end-use modelling can be used to predict future water demand. This technique can also be

applied to estimate the effect of different water conservation measures on demand and prepare plans for use in very dry periods or other emergencies affecting the availability of water.

End-use modelling can be expanded to include various factors such as plumbing codes, conservation measures, emergency conservation and cost-benefit analyses. As with all types of modelling, the quality of the input data is of the highest importance to obtain accurate results from the analyses.

The study showed that end-use modelling is a powerful tool for estimating future water demand that can be of great benefit to a bulk water supplier like Rand Water for planning and emergency preparedness purposes.

This pilot study was aimed at demonstrating the principles and potential application of end-use modelling. A number of assumptions and simplifications were therefore made. To obtain meaningful results from an end-use demand model, the following points should be considered:

- Additional water use categories should be defined beyond 'townships' and 'suburbs', such as business districts, industries, parks, schools, flats and townhouses. The water use for each category needs to be conceptualised to obtain an appropriate modelling approach.
- The simple 'indoor/outdoor' split may have to be extended to include pools, washing machines, dishwashers, etc.

- With the extension of the model, there also comes the need for calibration of the increasing number of model parameters. However daunting this may seem, this study showed how a systematic analysis of the scant data available can render a fairly robust set of model parameters, even for such notoriously whimsical parameters as income elasticity.
- The water demand of informal settlements is particularly troublesome from a modelling perspective. A special effort will be required to reach consensus of how non-payment and free water can be incorporated in a realistic model.
- It seems inevitable that even the best parameter estimates will be bounded by a defined band of uncertainty. It was already pointed out that the upper and lower estimates in the hypothetical case study presented are unrealistic – one would not expect all four model parameters to be simultaneously low or high. As more parameters are introduced, it will become necessary to apply a probabilistic technique such as Monte Carlo Simulation to make more realistic estimates of area-wide water consumption.

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