The first reported correlation between end-use estimates of residential water demand and measured use in South Africa

HE Jacobs
Department of Civil Engineering, University of Stellenbosch, Private Bag X1, Matieland, 7602, South Africa

Abstract

End-use modelling of residential water demand is becoming increasingly relevant. It encourages better understanding of how water is used by end users. Such an understanding is invaluable in view of improved water use efficiency and savings. This paper reports on the practical application of end-use modelling. The sample correlation between end-use-based estimates of water demand and metered consumption for specific residential customers is investigated. Two datasets are used in this investigation. The first comprises 11 customers in Stellenbosch who volunteered to take part in a detailed pilot study. The second group comprises users from 120 high-density, low-income dwellings in four different communities in Cape Town voluntarily responding to a once-off field survey. The paper presents findings regarding the practical application of end-use modelling. The results show that the end-use estimates of demand for the pilot study group correlate reasonably well to metered consumption, but that this does not hold for the high-density, low-income group. This is the first reported work of its kind in South Africa, where the sample correlation between end-use-based estimates of demand and metered consumption is investigated.

Keywords: residential water consumption – mathematical models, end-use estimates

List of abbreviations and acronyms

AMDD	average monthly daily water demand (ℓ/stand·d)
AADD	average annual daily water demand (ℓ/stand·d)
CVA	contingent valuation approach
GIS	geographic information system
HDLI	high-density, low-income (study group)
ℓ/cap·d	litres *per capita* per day (unit of measurement for unit water demand)
ℓ/d	litres per day (unit of measurement for water demand)
PPH	people per household (unit of measurement for household size)
RDP	Reconstruction and Development Programme
REUM	residential end-use model (described in this paper)
WDM	water demand management

Introduction

The application of end-use models is a key to better understanding residential water demand and water saving. The potential application of end-use modelling in South Africa has been noted in the past (Van Zyl et al., 2003) and is becoming increasingly relevant. In this paper an end-use is defined as the point (a device or element such as the bath or toilet) within the property of a residential consumer where water is released from a pressurised water supply system to atmospheric pressure. The term, 'micro-component', is also used in the literature to describe water use at this resolution. This paper focuses on practical application of end-use modelling.

In theory it should be possible for consumers to accurately estimate their own residential water demand, based on the end-use approach: by estimating input parameter values required for populating the model (for example the toilet flush volume, shower duration, lawn surface area, etc.). This paper addresses the question, 'Do consumers have the ability to predict their own water demand, based on a prediction of end-use parameter values, and what could be learned from such practical application of end-use modelling?'

In order to address this question a two-fold approach is followed in this study. Firstly, end-users in two study groups are asked to estimate values relating to the end-use model input structure (by completing a questionnaire), that are in turn used to conduct an end-use modelling exercise to estimate the demand for each user. Secondly, the metered water consumption for the same users is recorded, analysed and compared to the end-use-based estimates. The focus of the study and analysis is limited to the two sample groups, thus making no claims about the water use of consumers in general.

Previously Jacobs and Haarhoff (2004b) investigated the practical application of end-use modelling, but that study was based on 'baseline' input values for end-uses instead of on estimates for end-use model parameter values obtained directly from end-users, as is the case in this study. Van Zyl et al. (2006) recently completed a detailed analysis of water consumption in South Africa, but their work does not provide resolution to the level of end-uses at individual properties. This is the first reported work of its kind in South Africa, where the correlation between end-use-based estimates of demand and metered consumption is investigated.

Methodology

The study includes a comprehensive desk-top review of available literature, design of an appropriate and practical method for surveying end-uses of demand, experimental set-up with two study groups and correlation between estimated and metered water demand for the two study groups. Based on the findings, various conclusions are drawn and future work is identified.

The methodology applied in this study comprises the following steps, listed chronologically:

---

* To whom all correspondence should be addressed.
☎ +27 21 808-4059; fax: +27 21 808-4351;
e-mail: hejacobs@sun.ac.za

Received 24 August 2006; accepted in revised form 30 March 2007.

1. Select an end-use model pilot study group, with a focus on users who have a good knowledge and understanding of the end-use process and are considered likely to provide good estimates for their own end-use model input parameters.
2. Obtain end-use model input parameters for each member of the pilot study group.
3. Conduct an end-use modelling exercise and subsequent aggregation of monthly results to obtain estimates of the annual average daily demand (AADD) for each member of the pilot study group.
4. Spatially identify the individual users, selected during Step 1, in a geographic information system (GIS).
5. Obtain information regarding the monthly water consumption of these individual users from the system database containing individual water meter readings.
6. Analyse the above meter readings to obtain the metered water consumption for each user.
7. Correlate the end-use-based estimates to the metered consumption.
8. Repeat Steps 1 to 7 for a larger homogeneous, less-informed group of users from high-density, low-income (HDLI) residential dwellings (on condition that the initial findings are encouraging).
9. Conduct additional analyses to explain the findings and reach conclusions regarding the results.

Experimental design

Overview

The experimental design is based on the concept of estimating end-uses of residential water demand and subsequent methods to model the demand. The proper design of the end-use experiment relies on selection of a suitable study group, choice of an appropriate end-use model and suitable, effective yet practical method to obtain model input parameter values. In this manner monthly results of water use, broken down by end-use, are obtained from the residential end-use model for each individual consumer partaking in the study.

Metered water use

In addition to the end-use information, this study set an objective to obtain metered water use for each water user in the group. The monthly metered consumption for each user is obtained from the municipal water meter located at the property boundary, via the treasury system and water demand management software. This treasury-based process includes built-in verification methods and was applied by Jacobs et al. (2004) to analyse metered use during a comprehensive study of water demand. It has also recently been exploited to compile a national water consumption archive (Van Zyl and Geustyn, 2006) and to produce updated estimates for demand based on stand size and property value (Van Zyl et al., 2006). No additional cleaning or verification of metered use was conducted during this study.

End-use model and model input parameters

Jacobs and Haarhoff (2004a) provide the mathematical structure of a residential end-use model (REUM) selected for use during this project. The model input structure is well-suited to be transformed to a user-friendly questionnaire. The same authors also discuss prioritisation of the model input parameters (Jacobs and Haarhoff, 2007) and discuss potential application of the model (Jacobs and Haarhoff, 2004b). Other end-use models have been discussed in the past (Butler, 1991) and commercial packages have been used with success in South Africa (Castillo and Garbharran, 2003). However, REUM is preferred, because it was developed locally, the structure of the model encourages inputs based on a contingent valuation approach (CVA) and the model is available free of charge.

Choice of a particular model is not considered critical for this analysis, as long as the model is capable of providing end-use-based estimates of monthly water demand, as is the case with REUM. However, thorough data collection, with specific attention to the most notable parameters, is essential. Jacobs and Haarhoff (2007) note household size and parameters describing lawn water irrigation as most notable in view of predicting indoor demand and outdoor demand respectively.

Pilot study group

The first phase of the application involves a pilot study group of 11 residential consumers in Stellenbosch. It was considered appropriate to select participants with a technical background, thus with a good knowledge of their own water use. This approach was also followed by Garlipp (1979) during a previous study regarding water use.

Consumers were selected for the pilot study group based on each user meeting the following criteria:

- Commitment to the programme, despite a lack of compensation.
- Study group members are individual home owners in the Stellenbosch Municipal area with a technical background.
- Sustained 2-year period regarding water use behaviour and property description.
- Availability of an accurate, uninterrupted and complete 2-year water meter record from the Municipal treasury system.
- Variation in property type and usage patterns. Ideally, the range of uses should include outdoor irrigation of lawn and garden beds, with some variability over the entire range of property size and water use.

The stringent selection criteria resulted in selection of only 11 members to the pilot study group, but one of the group members eventually dropped out and could not be used during the analysis. All members of the pilot study group had personal contact with a member of the project team, enabling the researchers to maintain regular contact. The property size of users in the pilot study group varied between 275 m^2 and 3 200 m^2.

High-density, low-income (HDLI) study group

Subsequently, a high-density, low-income (HDLI) study group was selected. The dwelling-type for residences in this study group is often referred to as an 'RDP-house' (after the Reconstruction and Development Programme of the South African government). This type of dwelling is typical of a large and growing segment of the residential consumer group in South Africa. The group was chosen for analysis instead of another group from the low-density residential sector, because knowledge of water use by HDLI-users is considered to be valuable and also because demand for these users is mainly indoor-based. The component for outdoor water demand – which is considered to be harder to predict by means of end-use modelling – is negligible (Veck and Bill, 2000).

The study group was selected by considering the following aspects:

- Four different locations with similar dwelling types were selected after careful consideration of the City of Cape Town GIS information.
- Minimal commitment to the programme was expected. Group members would have to complete one survey questionnaire.
- Availability of an accurate, uninterrupted and complete 1-year water meter record from the municipal treasury system.

After initial selection of the HDLI study group members, 120 properties in four different residential areas in the City of Cape Town were visited by staff members. The four areas, with the number of responses received from each area in brackets, are: Heinz Park, Mitchells Plain (37), Brown's Farm, Philippi (40), Vygiekraal, Athlone (20) and Fisantekraal, Durbanville (20). Four of these 117 responses received could not be linked to a water meter record in the treasury system and had to be discarded. No responses were discarded on the basis of appearing 'incorrect' and the remaining 113 were included in the subsequent analysis. The property size of the dwellings in the HDLI study group varies between 80 m^2 and 280 m^2 with an average property size of 145 m^2.

Contingent valuation approach (CVA) in combination with metered use

The input parameter values for some of the model input parameters are based on a contingent valuation by each household. The information was obtained by means of a carefully designed questionnaire, discussed by Sinske et al. (2006). The questionnaires were distributed electronically to the pilot study group. However, in the case of the HDLI group the water users were individually targeted during a site visit. Each user was assisted with the questionnaire during this process and in all cases the survey was completed 'on site' during a door-to-door process by a staff member of one of the firms involved in the study.

Transformation and verification of input data

Transformation of data from the questionnaire to the model input is a relatively uncomplicated process, involving data entry to electronic media as a first step. Further transformation of this raw data is necessary (e.g. transformation of 'Y' to one and 'N' to zero) in view of model input, although some more complex transformations are included in the process prior to modelling (e.g. transformation of event and frequency parameters to *per capita* terms). In addition to this transformation of inputs, a screening exercise was included for the pilot study group to identify data inputs that appeared to be erroneous. One notable problematic input centred on the input parameter describing bath and shower event frequency. This aspect warrants some discussion.

Members of the pilot study group misunderstood the wording of the question on bath and shower use frequency (the two parameters are required in *per capita* terms). These event frequencies are obviously related, since both end-uses serve the same function (cleaning the body). Subsequently, all the pilot study group members' input values for these two parameters were re-evaluated and corrected where errors to the initial model input were present. This was made possible by the continued commitment of the relatively small group to the project. With prior knowledge of the problem, staff members were alerted to clearly explain the relationship between the bath and shower frequency to HDLI respondents during the data-gathering phase.

In both cases (the two study groups) iteration of input data was not conducted. In other words, the responses to the end-use questionnaire were used as an input to the model and subsequently for data analysis, without iterative amendment to the inputs. The model result was not shown to the respondents in order to amend input values and achieve a more accurate result.

Limitations and basic assumptions

Modelling process

The frequency resolution of the study is monthly, using at least 12 consecutive months' data to allow for investigation into average monthly daily water demand (AMDD) and AADD. However, it was considered appropriate to obtain and apply average annual parameter values for those end-use model input parameters where annual variation was not considered to be significant.

Weather variables (e.g. rainfall and evaporation) used in this study to populate input parameter values for the outdoor model component are based on long-term average values and are not limited to the period corresponding to the time of record. The weather stations at Stellenbosch and Cape Town International Airport provided adequate data for this purpose for the pilot study and HDLI study groups respectively.

Study group size

The pilot study group comprised 10 good samples of 11 responses, while the HDLI study group comprised 113 responses out of a total of 120 houses visited. This relatively small group size is not uncommon in studies where end-use of water at residential properties is investigated. Table 1 (next page) lists the study group size of other end-use investigations and also includes the methodology used to obtain the results in each case. The detailed nature of such studies implies that substantial effort and cost are required to increase the number of participants in the group and the accuracy of the method used. Table 1 shows that, in one case, findings regarding end-uses of water are based on a desk top review, while a maximum of 2 000 homes are included in another. The methodologies used vary from detailed measurements at high frequency, implying a relatively high study cost, to the less accurate, cheaper method of contingent valuation. The monthly frequency used in this study compares well to other work, where frequency varies between 10s logging intervals and annual average results. In South Africa the annual average value is most common.

The sample size of both groups in this study is considered adequate to ensure interesting and accurate findings regarding end-uses of water within the sample, and regarding the end-use modelling process in general. This information is especially valuable in identifying and prioritising future research needs.

Contingent valuation approach (CVA)

Some model input parameters are populated by means of contingent valuation, which relies on the perception of an individual regarding a certain matter. This approach could be viewed as a limitation in its own right. However, Veck and Bill (2000) used a CVA to estimate the price elasticity of water and Cameron and Wright (1990) investigated retrofit activity in the same manner.

TABLE 1
Study group sizes for some other end-use studies of residential demand

Literature reference	Study location and methodology		Group size (homes)
Ball et al., 2003	International	UK, 10 different supply areas, uncertain	250
DeOreo et al., 2001		USA, Seattle, metered	37
Mayer et al., 1999		USA, contingent valuation (survey)	1188
Achttienribbe, 1998		Netherlands, contingent valuation (survey)	2000
DeOreo et al., 1996		USA, Boulder, metered, 10s intervals	16
Edwards & Martin, 1995		UK, metered end-uses, 15s intervals	100
Butler, 1991		UK, contingent valuation (survey)	28
Schutte & Pretorius, 1997	SA	Limited to desk top study, annual average	-
Van Schalkwyk, 1996		CVA-approach (interviews), annual average	± 100
Garlipp, 1979		CVA-approach (group: engineers), annual ave.	± 300
Veck & Bill, 2000		CVA-approach, annual average	150
This study, Pilot group		CVA-approach and metered, monthly	113 (of 120)
This study, HDLI group		CVA-approach and metered, monthly	10 (of 11)

In this study the approach is applied to obtain values for end-use model input parameters that are subject to consumer behaviour and also those parameters that are considered atypical with regards to physical property description.

CVA is commonly encountered in South African literature on end-uses of demand, probably because this method is not as expensive to implement as methods based on measured water use (refer to Table 1 for references). In this study contingent-based estimates for end-uses of demand are used in combination with metered water use at each property.

Correlation and selectivity bias

Correlation is a measure of the degree of linear association between two parameters. It allows for the investigation of the relationship between the variables, but does not imply causative relation between them – one cannot be used to predict the other. The sample population coefficient, r, is used in this study to describe the correlation between estimated and metered water demand in each of the sample groups, instead of a population correlation coefficient that would be representative of the larger populations from which the samples were taken. This limitation allows for relatively uncomplicated statistics, as no attempt is made at this stage to evaluate the 'truthfulness' of the result in providing information about the population from which the samples were taken. This assumption implies that the results of both end-use study groups are not applicable to users outside the study groups. Subsequently the results are not claimed to typify other water users, despite such users possibly displaying similar characteristics to the water users in the study groups.

Calculation of the sample population coefficient is based on least squares fit to a scatter plot of the data. Values of r could vary between the extremes of perfect negative correlation where $r = -1$ and perfect positive correlation where $r = 1$. A zero value would imply no correlation. Finally, it is assumed that both parameters investigated are normally distributed random variables.

Also, Cameron and Wright (1990) noted that study groups for water demand, comprising members who volunteer to take part in a study (as is the case here), might be biased due to such group members being more likely to engage in behavioural changes that reduce demand. In addition, the pilot study group comprises members with a thorough technical background. The profile of the pilot study group is not considered to be representative of the larger population.

The HDLI-type dwellings, with limited outdoor use, are considered to be similar in physical description to other HDLI-dwellings in South Africa. However, as is the case with the pilot study group, no attempt is made in this study to typify the HDLI study group to represent other HDLI-type consumers.

The relatively small sample group, particularly in the case of the pilot study, calls for caution regarding biases that might only be identified if the sample group size were increased in order to extend the result to a larger population with statistical significance. However, bias is not a concern in this study *per se*, because the attention is focused on the users within the sample instead of on application of the results to the larger population.

Water leaks

Water leaks on properties (so-called 'plumbing leaks') are not included in the end-use modelling process. The model has the capability to include 'leaks' as an end-use, but it was considered appropriate to conduct this investigation by assuming that no leaks were present. The relatively small pilot study group made inspection possible to confirm that visible leaks were insignificant, thus encouraging this approach. One property reported that a leak had been repaired prior to the completion of the questionnaire (Property D).

In the case of the HDLI study group, inspection of leaks was not possible within the financial and time constraints of this project. Requests by staff to enter the first few homes taking part in the survey were unsuccessful (owners did not permit entry). It was considered appropriate to remain consistent and not model leaks for these properties either.

Correlation in average annual daily demand

Pilot study group

The end-use estimates of AADD for members of the pilot study group are plotted against the corresponding measured AADD

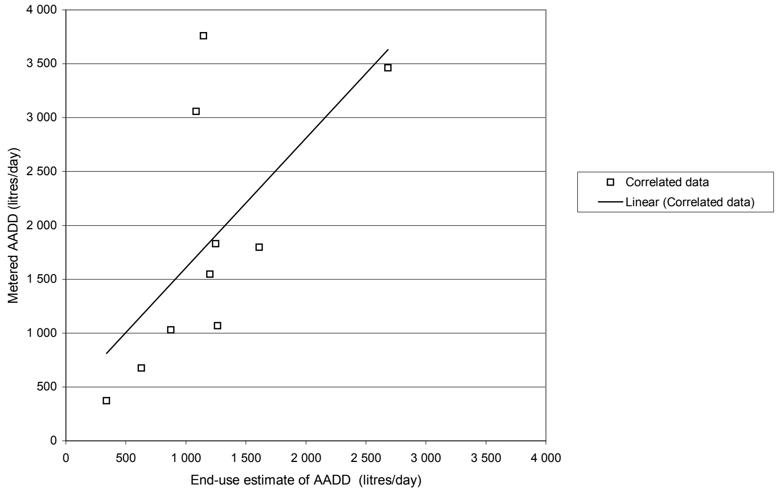

Figure 1
Pilot-study group
Correlation of estimated and metered AADD

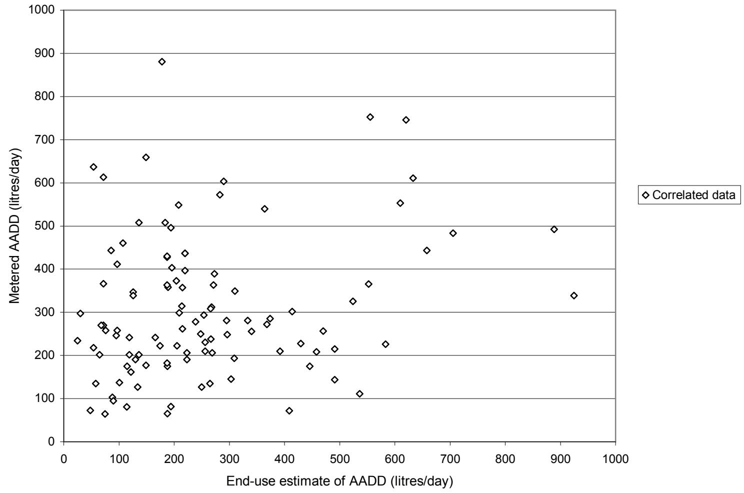

Figure 2
HDLI-study group
Correlation of estimated and metered AADD

in Fig. 1. The correlation coefficient *r* is 0.64 and suggests that end-users in the pilot study group with a relatively high metered AADD were able to estimate their AADD higher than those properties with a relatively lower AADD. Property D, reported to have had minor problems with a leak, significantly under-estimated its metered water use (about 3 000 ℓ/d), which was possibly higher than expected due to the leak. However, the data point is not discarded from the analysis. One other user also significantly under-estimated the metered use, but no apparent reason for the problem could be identified; the most likely explanations include the presence of an unknown leak or a water meter error.

In Fig.1 all but one of the results plotted above the 45-degree line, suggesting that most users in the group under-estimated their own AADD when estimating values for end-use input parameters. In all fairness to the pilot study members, the result is surprisingly good, assuming that no iteration was allowed – a result obtained by completing a questionnaire and thus estimating almost 50 input parameter values. On the other hand, it appears that an improved record-keeping of water-use habits and more detailed measurement of physical attributes (model input parameter values) would be required to provide a highly accurate result.

HDLI study group

In the HDLI group a low coefficient was found for the correlation between the end-use-based estimate for AADD and the measured AADD, as shown in Fig. 2. The value for *r* is 0.20. This might be ascribed to various factors:

- Leaks – leaks in high-density areas are generally known to be common and highly variable from one property to the next and could contribute to the poor correlation.
- Poor input values – possible inaccuracy of the model inputs obtained during the CVA due to users misunderstanding the questionnaire.
- Erroneous metered data – the accuracy of metered data obtained from the treasury system could be suspect (many users in this group use less than 6 kℓ/month and thus obtain free water with no incentive to verify water use recorded on a water account).
- Outdoor use – the presence of outdoor use is discounted as a possible explanation (inspection was conducted during the survey and aerial photographs of some properties were inspected).

Parameter values such as (say) toilet flush frequency, or shower event frequency could appear complex for individuals without a technical background, despite the simplistic wording of questions to obtain the values. More confidence could be placed in those parameter values that are considered easy to describe, for example by counting. The household size is such a parameter and is also listed first in the questionnaire, suggesting that it could have received priority attention during a response. Attention is briefly turned to this parameter.

Household size

Household size is known to be a strong determinant of water demand (Danielson, 1979; Butler and Memon, 2006). Household size was also identified by Jacobs and Haarhoff (2007) as being the most significant determinant of indoor demand, hot-water demand and wastewater flow, during a prioritisation of all REUM input parameters.

Figure 3 is a scatter graph of all AADD-values against household size for the 113 respondents of the HDLI study group. The water demand for these users is considered to represent mainly indoor type end-uses, due to the lack of gardens at these dwellings. The 11 results for the pilot study group are excluded due to the presence of outdoor use in these cases. Some relatively high values are noted in Fig. 3 that could be ascribed to excessive leaks at those properties, but the points are not discarded as outliers in this analysis.

With consideration of a single household size, a distribution of the data could be obtained. A frequency distribution histogram of the 43 responses for a household size of (say) 5 PPH is presented in Fig. 4. Despite the relatively few data points the form of the distribution could be considered to be approximately normal. The average value for the demand in this household size

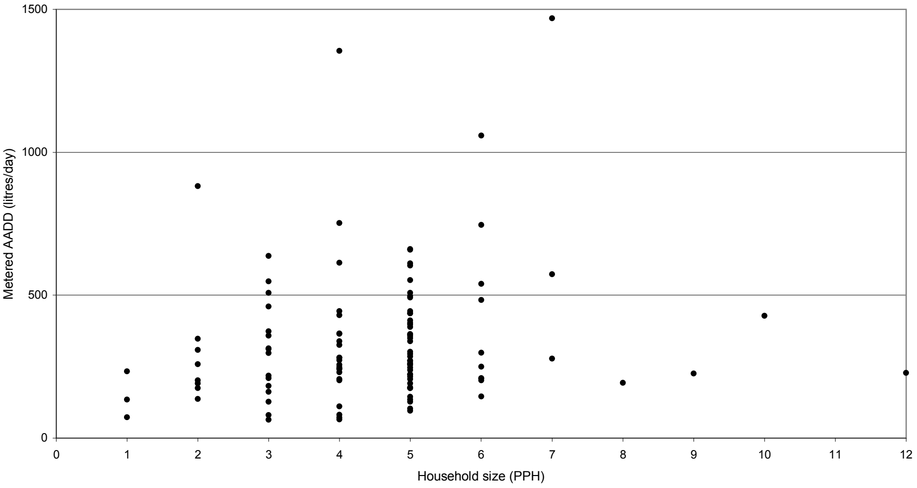

Figure 3
Correlation between household size and measured water use for the HDLI-study group (Total of 113 responses in group)

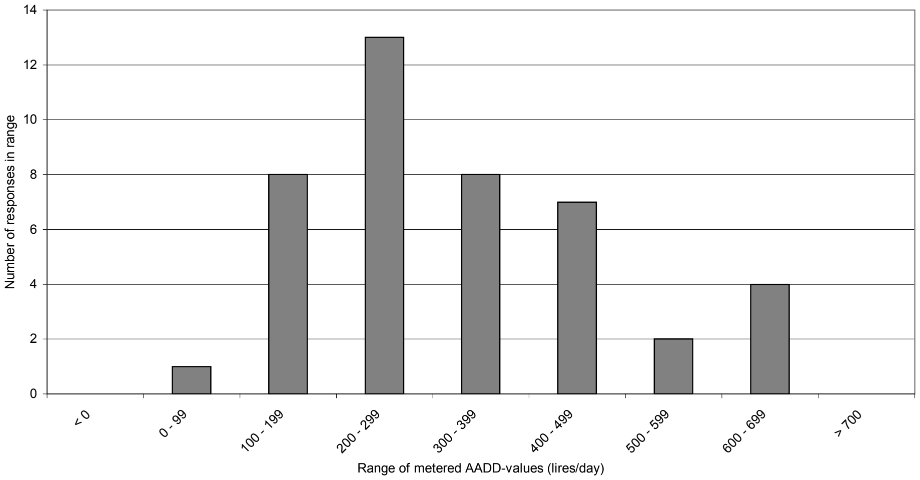

Figure 4
Distribution of water use for HDLI-responses with household size of 5 PPH (Total of 43 responses in group)

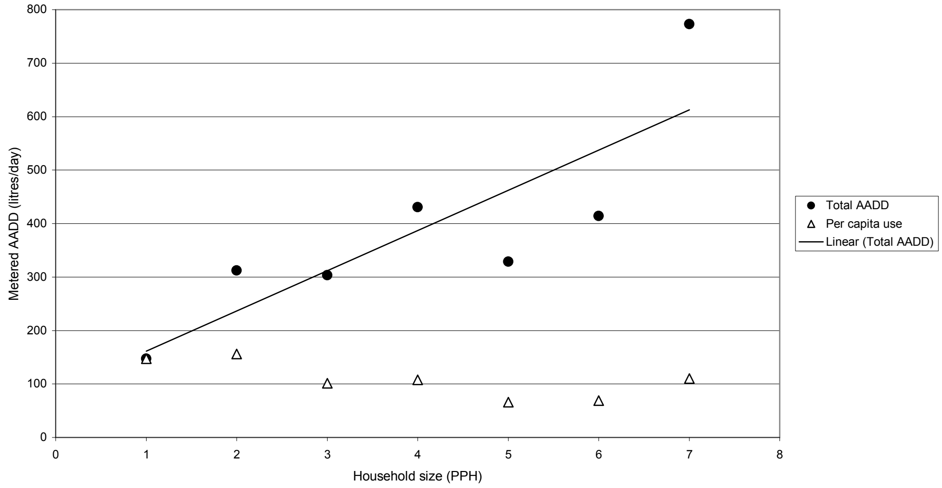

Figure 5
HDLI-study Group – Measured average AADD versus household size (Total of 113 responses in group; limited to household size of 7 PPH)

category is 329 ℓ/d. The average value for the AADD in this household size category could be used, with similar results for the other household size categories, to construct a plot of the average demand in each household size category, as shown in Fig. 5. The X-axis is limited to a household size of 7 PPH, because very few data points are present in the larger categories.

The least-squares fit to the data has an approximate linear form with an r^2 value of 0.7. A transformation of the results to *per capita* terms is also included in Fig. 5 as triangular points, showing that the average *per capita* use varies between a low of 66 ℓ/cap·d for 5PPH and a maximum value of 156 ℓ/cap·d for 2PPH. The average value for *per capita* use over all categories is 108 ℓ/cap·d.

Investigation into seasonal use

Base use component

Seasonal cycles of use were only investigated for the pilot study group, because of the presence of garden irrigation. An interesting finding in this regard is that the lowest measured winter month's use in each year was practically the same for the two consecutive years' analysed during this investigation for each pilot study group member. In other words, each user in the study group displays a relatively constant 'base use' value that could be considered a minimum practical use for the particular user at the particular property. These lowest AMDD values for each of the users are shown in Table 2, with the corresponding household size and *per capita* use – based on the average of the two lowest values – also included for each user. The average *per capita* baseline use for the study group is 158 ℓ/cap·d. This concept of a base use with an absence of cycles, other than daily, is not new and has previously been reported by others (Edwards and Martin, 1995; Howe and Linaweaver, 1967). The low-season use is considered in this study as an indicator of the baseline use.

TABLE 2
Base use for pilot study group

Property	Household size (PPH)	Lowest metered AMDD during study period			
		AMDD (ℓ/d)	Recorded in	Average AMDD (ℓ/d)	Per capita AMDD (ℓ/cap·d)
A	5	700, 700	June, June	700	140
B	5	850, 900	June, July	875	175
C	6	no reading, 650	None, December	Note A	Note A
D	3	750, 750	June, May	750	250
E	4	600, 550	August, June	575	144
F	5	750, 800	June, June	775	155
G	4	450, 450	June, May	450	113
H	3	450, 500	May, June	475	158
J	1	150, 200	June, July	175	175
K	5	850, 750	June, June	800	160
L	2	250, 200	July, July	225	113
				Average =	158

Notes:

A) Property C was not used in analysis (refer to text)

Minimum winter use

A scatter plot of the measured lowest winter month's consumption for the pilot study group is plotted against the corresponding end-use model result for the lowest month in Fig. 6 (a similar result – not presented here – is obtained if the lowest three-month period is used to present the winter seasonal use, instead of the lowest month). The correlation coefficient *r* is 0.61. The end-use result is obtained by calculating the AMDD for all end-uses (indoor and outdoor) for the lowest winter month, keeping in mind that the outdoor use component is negligible at that time of the year (the Western Cape is a winter rainfall region). The relatively flat slope of the linear fit to the data suggests that the users in the pilot study group tend to over-estimate their baseline demand.

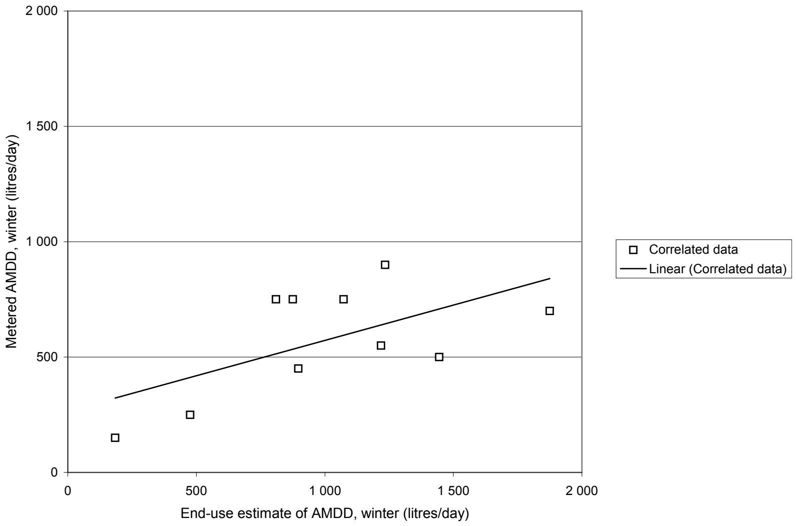

Figure 6
Pilot-study group – Correlation of minimum winter demand (lowest month)

Indoor component and baseline use

The obvious conclusion that the baseline use represents 'indoor use' was reported years ago by Howe and Linaweaver (1967). Figure 7 shows the correlation between the metered baseline use and the end-use estimate for the indoor use component. The latter is calculated as the AADD for all indoor type end-use combined. The result is similar to Fig. 6, as could be expected, although two different calculation methods are used to estimate the end-use component in the two cases.

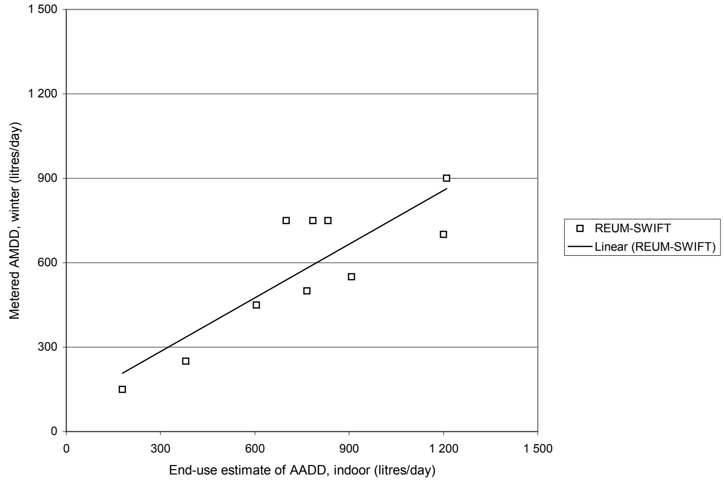

Figure 7
Pilot-study group – Correlation between estimated indoor AADD and base use

Summer seasonal use

Summer seasonal demand is known to be influenced by outdoor use, which is consid-

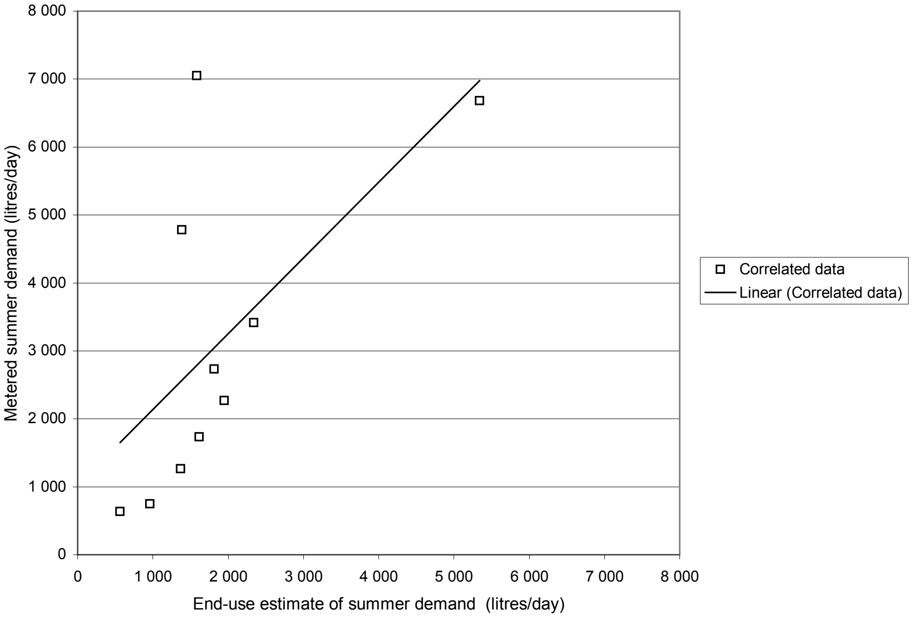

Figure 8
Pilot-study group
Correlation for
3-monthly average
summer demand

TABLE 3
Summary of sample correlation coefficients

Description of sample	Scatter plot	Description: Correlation between		r
		REUM-estimate	Metered data	
Pilot-study group	Figure 1	AADD, total	AADD, total	0,64
HDLI-study group	Figure 2	AADD, total	AADD, total	0,20
Pilot-study group	Figure 6	AMDD, total mid-winter	AMDD, total mid-winter	0,61
Pilot-study group	Figure 7	AADD, indoor only	AADD, total base use	0,85
Pilot-study group	Figure 8	3-Mnth AMDD, summer	3-Mnth AMDD, summer	0,63

ered to be hard to predict. In addition, meter reading is often neglected in South Africa over the December holiday period, suggesting that a longer period should be used to accurately reflect the summer seasonal use. The 3-monthly average summer use is considered an appropriate measure to obtain insight into summer seasonal use, instead of using the single maximum month's data. The result is presented in Fig. 8. It appears that users under-estimated their summer use. The two users previously identified in Fig. 1 also significantly under-estimate their (summer) use.

Discussion

A summary of the sample correlation coefficients presented in this paper is shown in Table 3. The values for *r* vary between 0.20 and 0.85. The best result is achieved for the pilot study group, with the larger HDLI group showing poor correlation. This is not surprising when it is considered that the pilot study group members were more committed to the study than those in the HDLI group.

Significantly different findings for the two study groups can most likely be explained by one or more of the following:

- The capability of end-users to accurately describe their water use versus a lack of such capability. It is likely that the members of the pilot study group, with a good technical background, have a better understanding of their own water use habits and are thus able to provide a more accurate description of model input parameter values than the members of the HDLI study group.
- Leaks at properties are included in the metered component for some users, but not in the end-use estimates. It has been reported that leaks are prevalent in HDLI-type communities, thus suggesting that water leakages on individual properties may contribute substantially to the explanation for the different results found for the two study groups.
- An increased volume of erroneous metered use records percolating through the system for users in the HDLI group, where water is free and little incentive exists for users to inspect, verify and correct potential errors in billed water use. This is in stark contrast to the pilot study group members who regularly keep a keen eye on their recorded use, encouraged by their technical background and level of payment.

Conclusion

This small-scale study suggests that there is promise of practical application for end-use modelling at end-user level, but also suggests that improvement in the data gathering and modelling process is required. The end-use model results provide reasonable correlation to metered demand for the water users in the pilot study group. To confirm findings of this study in general the work should be extended to include a larger sample. Such work should incorporate leakage data and could make use of an improved iterative CVA data input structure. Despite knowledge of selectivity bias, a group with technical background could be expected to produce better estimates for demand than a non-technical group.

The indoor estimate of use in the pilot study group and baseline water use provides the best correlation. This finding supports the perception that it is more difficult for a consumer to estimate end-use parameters describing outdoor water use than indoor water use and thus that it is more difficult to accurately model outdoor end-uses of water than indoor end-uses.

Improvement of CVA as a method to gather input parameter values for end-use modelling is possible. Sinske et al. (2006) and Sparks et al. (2006) noted that iteration could practically be incorporated in end-use studies by application of an internet web page, where the user would complete information regarding end-uses. The result of the end-use calculation, based on user-inputs regarding end-uses of water at the property, would then immediately be displayed at the click of a button. In addition, the monthly end-use-based results could be compared to metered consumption in the form of a table or graph (for example, as a value expressed in kℓ/month). At this point in the process an iterative component would be added, because the user would have the ability to reconsider and amend input parameters and re-run the calculation, until the end-use estimate and metered values correspond satisfactorily. However, an iterative process has not yet been included in either of the web pages discussed by those authors and it was only speculated by both that such an iterative process would lead to an improvement in the end-use-based estimate. In combination, future research could focus on the accuracy of metered use obtained from treasury systems, since metered use obtained from this source would form an integral part of such an iterative procedure.

Two methods are considered most appropriate for addressing leaks. Firstly, properties selected for study could be approached individually in order to inspect and repair (or measure) water leaks, prior to initiation of the work. Alternatively, if budget constraints limit the former method, properties with leaks could merely be identified during the selection process and discarded prior to inclusion in a study group. In either case, knowledge of leaks at properties is essential and should receive future research focus.

Despite the poor correlation between estimated and metered AADD for the HDLI group, the household size corresponds well to the average metered AADD, under-pinning the knowledge that household size is a strong driver of indoor water demand. Application of household size as a determinant in demand estimations should receive priority attention, in addition to other parameters, such as stand size (Jacobs et al., 2004). The application of end-use modelling, with household size being the main input parameter, should be considered during a future study. Exclusive focus on household size and other main contributing parameters during end-use analysis would enable substantial simplification of the survey questionnaire. In such an analysis all other input parameter values would be populated with 'typical' values describing the homogeneous properties being investigated. Identification of typical values for minor parameters describing different property types is a challenge for future research, but focus should first be placed on the most notable parameters.

Apart from the application of REUM as a tool to conduct end-use modelling, the educational value of REUM as a 'hands-on' tool for training water users at the end-user level should not be under-estimated. Application of the tool in a user-friendly web-based format could empower water users to learn more about end-uses and where the potential exists to save a precious and limited natural resource – water.

Acknowledgements

The author would like to acknowledge contributions and assistance by the following individuals and institutions: Dr BF Loubser and Dr LC Geustyn for significant contributions to the study, with reference to the pilot study group and HDLI group respectively; the City of Cape Town for making the data available for analysis; GLS Civil Consulting Engineers (Stellenbosch) and Africon (Cape Town) who managed and performed the data gathering of the pilot study and HDLI groups respectively.

References

BUTLER D and MEMON FA (2006) *Water Demand Management.* IWA Publishing, 2006.

BUTLER D (1991) A small-scale study of wastewater discharges from domestic appliances. *Water Environ. Manage. J.* **5** (4) 178-185.

CAMERON TA and WRIGHT MB (1990) Determinants of household water conservation retrofit activity: A discrete choice model using survey data. *Water Resour. Res.* **26** (2) 179-188.

CASTILLO G and GARBHARRAN HP (2003) The IWR-MAIN water model and its applicability for water provision to squatter communities in KwaZulu-Natal. Illustrated Paper Session: 5508. *South Africa into the 21st Century.* Association of American Geographers.

DANIELSON LE (1979) An analysis of residential demand for water using micro time-series data. *Water Resour. Res.* **15** (4) 763-767.

EDWARDS K and MARTIN L (1995) A methodology for surveying domestic water consumption. *Water Environ. Manage. J.* **9** 477-488.

GARLIPP DKCO (1979) Water Consumption Patterns in Urban Areas. M.Sc. Thesis, University of Pretoria, Water Research Group, Department of Chemical Engineering.

HOWE CW and LINAWEAVER FP (1967) The impact of price on residential water demand and its relation to system design and price structure. *Water Resour. Res.* **3** (1) 13-32.

JACOBS HE and HAARHOFF J (2007) Prioritisation of parameters influencing water use and wastewater flow. *J. AQUA*, accepted for publication.

JACOBS HE, GEUSTYN LC, LOUBSER BF and VAN DER MERWE B (2004) Estimating residential water demand in Southern Africa. *J. S. Afr. Inst. Civ. Eng.* **46** (4) 2-13.

JACOBS HE and HAARHOFF J (2004a) Structure and data requirements of an end-use model or residential water demand and return flow. *Water SA* **30** (3) 293-304.

JACOBS HE and HAARHOFF J (2004b) Application of a residential end-use model for estimating cold- and hot water demand, wastewater flow and TDS concentration. *Water SA* **30** (3) 305-316.

SINSKE AN, JACOBS HE and GEUSTYN LC (2006) Internet-based water demand management. In: *Proc. of the Water Institute of South Africa (WISA) Biennial Conference*. May 2006, Durban, South Africa.

SPARKS A, VAN ZYL B and CARR N (2006) Home water audit – a web-based tool promoting water awareness and allowing the collection of data on water use patterns. In: *Proc. of the Water Institute of South Africa (WISA) Biennial Conf.* May 2006, Durban.

VAN ZYL JE, HAARHOFF J and HUSSELMAN ML (2003) Potential application of end-use demand modelling in South Africa. *J. S.-Afr. Inst. Civ. Eng.* **45** (2).

VAN ZYL JE and GEUSTYN LC (2006) Development of a National Water Consumption Archive. Report for WRC Project No. K5/1605, Water Research Commission, Pretoria, South Africa.

VAN ZYL HJ, VAN ZYL JE, GEUSTYN LC, ILEMOBADE A and BUCKLE SJ (2006) Benchmarking of Water Consumption in Selected South African Cities. Report for WRC Project No. K5/1525. Water Research Commission, Pretoria, South Africa.

VECK GA and BILL MR (2000) Estimation of the Residential Price Elasticity of Demand for Water by Means of a Contingent Evaluation Approach. WRC Report No. 790/1/00. Water Research Commission, Pretoria, South Africa.