Prioritisation of parameters influencing residential water use and wastewater flow

H. E. Jacobs and J. Haarhoff

ABSTRACT

A residential end use model (REUM) which accounts for indoor water demand, outdoor water demand, hot water demand, wastewater flow and the mass of total dissolved substances (TDS) in the wastewater, was earlier described by the authors. The integral relationship between water quality and quantity in the model allows for holistic modelling of different water demand management measures' effects. The model covers 16 independent micro-components of water use and requires numerous model parameters. This paper has the objective to prioritise the 79 parameters which remain after stripping all possible redundancy from the model in terms of their relative impact. Two ranking criteria are used: the *elasticity* and the *sensitivity* of each parameter. The results, benchmarked to a typical South African suburban residence, show that household size is the most notable parameter for modelling the indoor water demand, hot water demand and wastewater flow volume. Pan evaporation and a factor describing actual lawn irrigation in relation to theory are most notable for modelling the outdoor demand. Wastewater TDS concentration is dominated by what is added at the toilet rather than pharmaceuticals and personal care products (PPCPs) added at other entry points to the wastewater system. The methodology developed and results obtained underpin the view that effective water demand management policies can only be rationally formulated with the assistance of a comprehensive water and wastewater model based on micro-components of water use.

Key words | residential hot water use, residential wastewater flow, residential wastewater salinity, residential water use, water demand elasticity index

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ABBREVIATIONS AND ACRONYMS

AADD	average annual daily water demand (ℓ/stand·d)
AMDC	average monthly daily concentration of TDS (mg/ℓ)
AMDD	average monthly daily water demand (ℓ/stand·d)
AMDF	average monthly daily wastewater flow (ℓ/stand·d)
AMDM	average monthly daily mass, of soluble substances (mg/stand·d)
a	binary flag to indicate whether the end-use is present / applicable (1) or not (0)
BATNEEC	best available technology not entailing excessive cost
BU	bottom up
b	volume parameter (ℓ/event/quantity)
c	frequency parameter (events/person/d or events/stand·d)
D	a dependent variable
DSM	demand side management (refer to WDM)
d	day
E	elasticity
e	end-use
F	an independent variable
f	garden irrigation factor, or factor for pool cover use

doi: 10.2166/aqua.2007.068

k	the empirical constant of proportionality between *p* and evapotranspiration known as the crop factor (it also represents the empirical constant of proportionality between *p* and the evaporation from the pool surface in the model)
ℓ/c·d	litres per capita (or person) per day
ℓ/d	litres per day
ℓ/stand·d	litres per stand (or property) per day
m	month (1 … 12, or January … December)
mg	milligram (unit of measurement for mass of soluble substances)
n	quantity parameter (household size, measured as the number of people per household)
PPCPs	pharmaceuticals and personal care products
PPH	people per household (unit of measurement for household size)
p	pan evaporation (mm/month)
R	actual, or measured, monthly rainfall (mm/month)
REUM	residential end-use model (described in this paper)
r	effective monthly rainfall (mm/month), as a function of rainfall (R)
S	sensitivity
s	surface area of vegetation type, or surface area of pool water (m^2)
T_B	blended ("desired") water temperature for end use *e* (°C)
T_C	cold water supply temperature ≈ ambient temperature (°C)
T_H	hot water supply temperature ≈ geyser temperature (°C)
TD	top down
TDS	total dissolved solids (mg/ℓ)
t	actual mass of soluble substances added to water (mg/event)
u	wastewater return factor (0 for no return and 1 for 100% return of water)
WDM	water demand management (akin to demand side management or DSM)
x	a variable
z	an integer value

Subscript

B	denotes *blended* (water)
C	denotes *cold* (water)
e	denotes *end-use*
H	denotes *hot* (water)
i	denotes indoor
m	denotes *month* (1 … 12, or January … December)
o	denotes *outdoor*
s	denotes soluble substance
w	denotes wastewater

INTRODUCTION

It is becoming increasingly important for all consumers to use water more efficiently. Residential consumers could be viewed as soft targets, often being the first to bear the brunt of water demand management (WDM) initiatives and restrictions during scarcity. Adopting terms from management, WDM measures implemented by a water authority could be viewed as top-down (TD) measures. Consumers are subsequently compelled, or at least encouraged, to implement some "bottom-up" (BU) WDM measures at home to react to the changes brought about by the water authority. Some conservation oriented consumers might even elect to implement BU measures at home without any additional incentives.

Changes in water use habits within a residence also influence hot water volume, return flow volume to the sewerage system and the quality of such wastewater, thus impacting on urban energy and wastewater management – an important linkage often neglected. For these reasons a residential end-use model (REUM) was developed earlier to evaluate WDM measures, with a focus on BU initiatives. The model was also used in this study. The model integrates five components of interest to urban managers: indoor water demand, outdoor water demand, hot water demand, wastewater flow and concentration of total dissolved solids (TDS) in the wastewater (Jacobs & Haarhoff 2004*a*).

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.

Kanakoudis (2002) notes that knowledge of parameters affecting urban water use is necessary in order for an urban water conservation programme to be successful. The end-use approach, on which REUM is based, considers individual micro-components of residential use and thus provides a high resolution for modelling the quantity of water used (Van Zyl *et al.* 2003; White *et al.* 2004; Butler & Memon 2006) and the quality after being used (Jacobs 2004).

This paper not only alerts the model user to those parameters which are most important, but also suggests focus points for water service providers to target consumers more effectively, or from the viewpoint of the end-user: where should the focus fall when asked to "save even more" water at home?

QUALITY CONSIDERATIONS

A parameter to evaluate water quality might seem out of place in a model used to evaluate WDM initiatives, but in fact its inclusion is considered crucial. A deterioration in water quality between the points of entry and exit to a residence is typically caused by the addition of soluble pharmaceuticals and personal care products (PPCPs) and human waste added at the toilet. Consider for example water used at a particular end-use, where the user is likely to pollute it with the same mass of soluble substances before and after a change in volume due to WDM-initiatives. In other words, a measure applied in the home to improve the efficiency of use by reducing the water quantity would imply a decreased quality of wastewater returned to the wastewater treatment plant.

For the purpose of this study it was considered appropriate to select one parameter to model the quality as including numerous parameters for water quality would distract from the focus of the work. The choice of this parameter – TDS concentration – does not imply that TDS is the most important (or only important) parameter for modelling quality, but it was considered a good and conservative indicator of quality for this purpose.

REUM (RESIDENTIAL END-USE MODEL) IN BRIEF

REUM, addressing a multitude of aspects in great detail, obviously requires a large number of model parameters – a total of 79 parameters remains after stripping all possible redundancies. This may raise the perception of a complicated, tedious model with little hope of practical application. However, a large fraction of the model parameters is populated quite easily with readily available information, as was shown before by Jacobs & Haarhoff (2004*b*).

Moreover, not all the parameters carry the same weight. In fact, many of the parameters have a disproportionately small influence on the model predictions. It is the purpose of this paper to prioritise the model parameters in order of their impact on the predictions for each component modelled.

REUM predicts monthly water demand, split into five components (Jacobs & Haarhoff 2004*a*). In South Africa the average annual daily demand (AADD) is regularly used as a basis for water demand- and distribution system analysis (Van Zyl *et al.* 2007). The average monthly daily demand (AMDD) could instead be considered when an increased resolution is required. In either case the demand is expressed as an "average daily" demand in kℓ/d. In the light of this background, the highest model frequency is in fact monthly, but model results are presented as average daily values.

Figure 1 is a schematic presentation of the model structure. The mathematical structure of REUM is summarized by five equations used to model five so-called "components". The equations for these five components – indoor demand, outdoor demand, hot water demand, wastewater flow and wastewater TDS concentration – are respectively:

$$AMDD_{i,m,e} = (a_e \cdot b_e \cdot c_e \cdot n) \tag{1}$$

$$AMDD_{o,m,e} = (f_{m,e} \cdot s_e) \frac{(k_{m,e} \cdot p_m) - r_m}{30.44} \tag{2}$$

$$AMDD_{h,m,e} = \frac{(T_B - T_H)}{(T_H - T_{C,m})} (a_e \cdot b_e \cdot c_e \cdot n) \tag{3}$$

$$AMDW_{w,m,e} = u_{m,e} \cdot (a_e \cdot b_e \cdot c_e \cdot n) \tag{4}$$

$$AMDM_{s,m,e} = t_{m,e} \cdot (a_e \cdot c_e \cdot n) \tag{5}$$

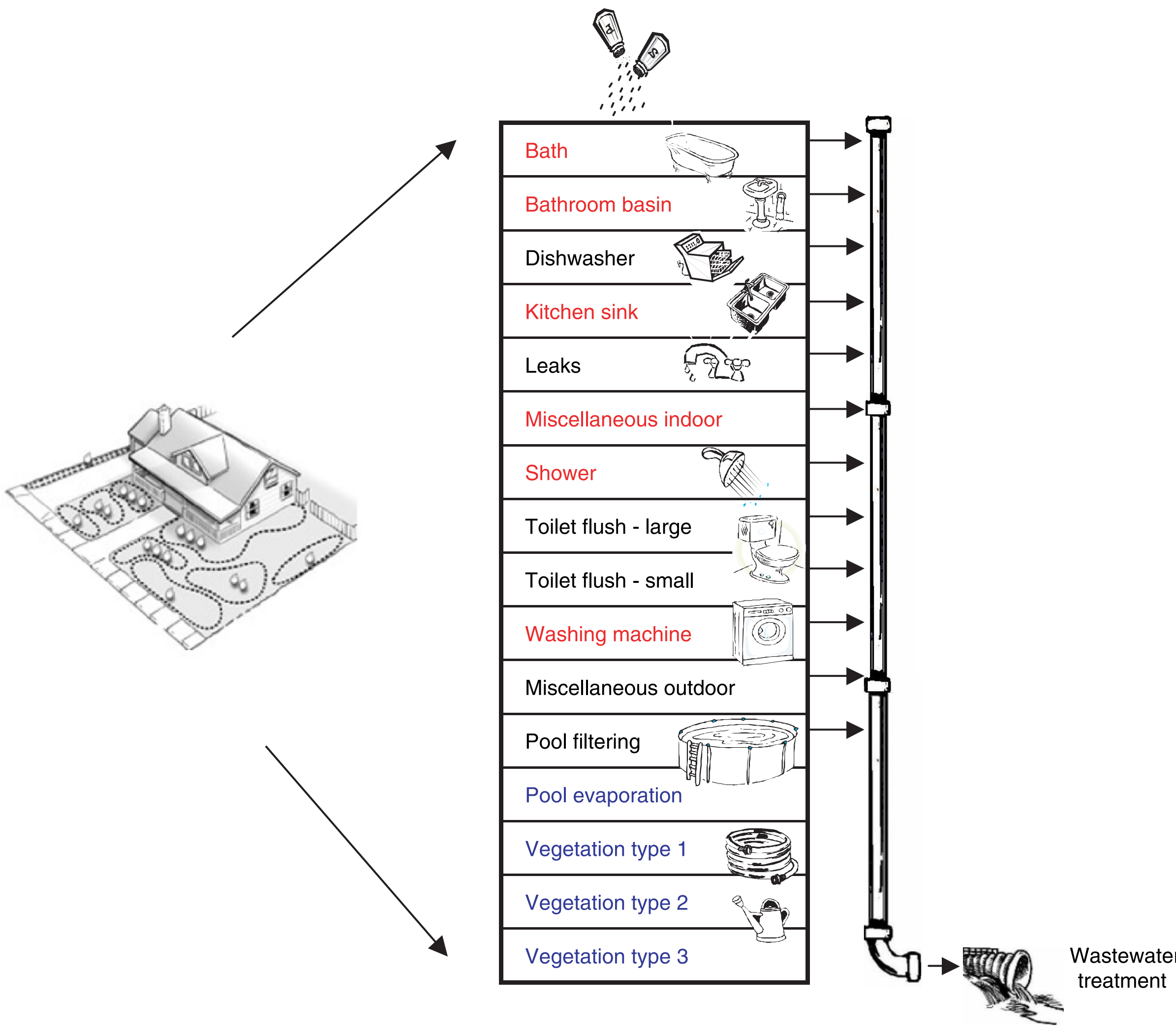

Figure 1 | Schematic presentation of the model structure.

These equations describe five dependent variables, addressed as a combined set termed D. The remaining notation and terminology used by Jacobs and Haarhoff (2004*a*,*b*) to describe the model parameters are adopted in this paper without change.

The 16 end-uses modelled in REUM are:

- Indoor: bath, bathroom basin, dishwasher, kitchen sink, shower, toilet (single flush and dual flush) and a washing machine.
- Outdoor: Pool (evaporation and filtering) and garden water use (allowing for three separate types of vegetation).
- Other: Miscellaneous indoor use, miscellaneous outdoor use and leaks. The term "leaks" is used in this paper to describe water leaks on the property of a residential consumer (often termed "plumbing leaks" in other literature). It does not incorporate water leaks in the supply system upstream of the consumer's water meter.

The hot water demand is modelled in REUM for all indoor type end-uses bar the toilet and leaks – deeper insight into hot water losses and their impact on energy use is provided by Lutz (2005). The term "blended water" is used to describe a mixture of hot water and cold water, delivered at a temperature desired by the end-user.

In order to ensure legibility of text, parameter subscripts in tables and figures are printed as an underscore character followed by the text to be subscripted, i.e. the parameter "c_{toilet}" would instead be indicated as "c_toilet".

PARAMETER EVALUATION

Elasticity

Parameter elasticity is a well established, quantitatively defined concept which comes from the field of economics and is often defined as a standardised measure of the sensitivity of one (dependent) variable to changes in another (independent) variable. The elasticity is valuable in order to describe response in a dimensionless, comparable way. Price is normally the independent parameter in the case of economics (Dibb *et al.* 2001) and studies pertaining to water demand (Stephenson 1999).

The concept of elasticity for other independent parameters – apart from price – is increasingly being used in the area of water management and has since been applied for parameters such as property size and system pressure (Danielson 1979; Van Zyl *et al.* 2003). It simply tells how fast a dependent parameter will change in response to an independent parameter:

$$Elasticity = \frac{(proportionate\ change\ in\ dependent\ parameter,\ e.g.\ quantity\ demanded)}{(proportionate\ change\ in\ independent\ parameter,\ e.g.\ price)} \quad (6)$$

Because the definition is based on proportionate changes, the result is a dimensionless number. Consider an example where the elasticity is 0.1: if the independent variable were to increase by 10%, one would observe an increase of approximately 1% in the dependent variable. Negative elasticity would imply a decrease. The word "approximately" is used because the exact result depends on whether the initial or final point is used in the calculation. The so-called arc elasticity, plainly termed "elasticity" (E) in this text, measures the average elasticity between two discrete points along the curve and is defined by:

$$E = \frac{(D_2 - D_1)/((D_1 + D_2)/2)}{(F_2 - F_1)/((F_1 + F_2)/2)} \quad (7)$$

where D_1, dependent variable before change;
D_2, dependent variable after change;
F_1, independent variable before change;
F_2, independent variable after change.

Sensitivity

Elasticity, as defined above, is a direct measure of how much the dependent parameter D will change in response to a change in the independent parameter chosen for analysis and is based on the parameter relationships as per the mathematical model description. However, it does not give a direct, practical measure of the water savings potential of a conservation initiative described by that parameter.

Some independent parameters can be arbitrarily varied by a consumer (e.g. shower duration), while others can only be varied over a very limited range (e.g. volume of water in a bathroom basin). The bath water temperature desired by a consumer, for example, is constrained by being uncomfortably cold or uncomfortably hot. In other words, the input parameters in engineering systems are often empirically restrained by the nature of the system.

This concept of system restraint is incorporated in the analyses by considering a so-called sensitivity, S. Typical low and high values of the independent variables in Equations (1) to (5) are used in each case to determine corresponding low and high values of the relevant dependent variable D. The sensitivity is then expressed by Jacobs (2004) as:

$$S = \frac{D_{high} - D_{low}}{(D_{high} + D_{low})/2} \quad (8)$$

where D_{high}, dependent variable with high value for relating independent variable;
D_{low}, dependent variable with low value for relating independent variable.

The parameter S thus incorporates empirical restraints due to the nature of the system. The use of parameter S provides added insight into the impact a change in any independent parameter value – from Equations (1) to (5) – has on the model result and consequently provides a more useful result in view of water saving potential and impacts than the elasticity.

RESEARCH METHODOLOGY

Screening of input parameters

Jacobs & Haarhoff (2004*a*) report that 79 input parameters are required to model all five components for each end-use, after making some assumptions to simplify the model structure. However, it is not necessary to investigate all these parameters. Scrutiny of the model structure suggests that only 49 of the 79 parameters (required for modelling one month) warrant further analysis. The remaining parameters and reasons for their exclusion are:

- All parameters relating to miscellaneous demand, as well as the dual toilet flush are excluded from the analysis. Subsequently the presence, volume and frequency parameters (a, b and c respectively) as well as the return parameters (u) and parameters describing the mass of soluble substances added (t) for these end-uses are not included. The reason for excluding these end-uses is that the miscellaneous end-uses are not required for a typical property, resulting in zero inputs. The change in parameter values for the toilet, investigated in this study, also describes the difference between normal and dual flush toilets. The dual flush is removed to prevent duplication of results. These assumptions lead to the exclusion of 15 parameters.
- The presence parameters (a) for the nine remaining end-uses modelled by the indoor equation are not adjusted. These values are binary by definition (either zero or one) and it makes no sense to adjust these values. Nine additional parameters are thus excluded.
- The frequency parameter for leaks is, per definition, equal to unity, requiring no adjustment.
- The analysis is simplified to include only two garden vegetation types (type 1 is used to model lawns and type 2 for garden beds), instead of three types allowed for in the model. The three parameters describing water demand for the third vegetation type are excluded.
- A return parameter for pool filtering is included in REUM, but it is not included in this analysis, because waste of backwashed pool water to the wastewater system does not occur often in practice due to physical constraints.
- No soluble substances are added at "leaks" (modelled as an end-use) and this parameter is excluded.

Model parameters – benchmarking against a "typical" residential property

Table 1 includes low, typical and high values for each parameter. The list was compiled after scrutiny of all data from an extensive literature survey, field measurements, analysis of consumer surveys and laboratory tests (Jacobs 2004). The work includes the review of 53 literature references in addition to information from 13 other sources, resulting in a total of 758 values for parameters directly pertaining to the model. All the values were grouped according to the model component and end-use. The typical values in Table 1 are the median of the most appropriate result set, as determined by Jacobs (2004). The low and high values are subjectively determined as the lowest and highest values expected to be recorded for a similar type of property to the one presented in this paper. Parameters with values which vary monthly (e.g. weather variables such as rainfall and evaporation) were obtained from sources such as the weather service and publications regarding crop water use.

It is necessary to select an appropriate point for analysis. A "typical" residential property was used by Jacobs & Haarhoff (2004*b*) to illustrate application of REUM to a property which is typical of a suburban setting in Johannesburg – the largest city in South Africa, situated in the inland (summer rainfall) region of the country. The AADD for the modelled property, based on the typical values as per Table 1, is 979 ℓ/stand·d. This result is similar to the AADD of 985 ℓ/stand·d obtained for Johannesburg by Jacobs *et al.* (2004) after analysing more than 100 000 suburban type residences' metered water use. The typical parameter values in Table 1 are adopted for this study to act as the base point for analysis.

Calculation of elasticity

It could be recalled that parameter D in Equation (7) represents any of the dependent variables from the five model components described by Equations (1) to (5), namely $AMDD_i$, $AMDD_o$, $AMDD_h$, $AMDW_w$, and $AMDM_s$. In order

Table 1 | 49 Parameters for residential water use model

	Parameter			**Values**		
End-Use	**Notation**	**Description**	**Unit**	**Low**	**Typical**	**High**
All	**n**	**Household size**	**PPH**	**1.0**	**3.0**	**5.0**
		COMPONENT 1 – MAINLY INDOOR WATER DEMAND				
		End-uses normally located outdoors				
Bath	b_bath	Event volume	ℓ/event	39.0	86.0	189.0
Bath (Note A)	c_bath	Frequency of use	events/c·d	0.22	0.24	0.90
Bathroom basin	b_bathroom basin	Event volume	ℓ/event	0.3	3.8	10.0
Bathroom basin	c_bathroom basin	Frequency of use	events/c·d	3.40	3.60	3.80
Dishwasher	b_dishwasher	Event volume	ℓ/event	15.1	25.0	43.0
Dishwasher	c_dishwasher	Frequency of use	events/c·d	0.18	0.25	0.29
Kitchen sink	b_kitchen sink	Event volume	ℓ/event	0.6	6.7	24.0
Kitchen sink	c_kitchen sink	Frequency of use	events/c·d	2.00	2.00	2.10
Leaks	b_leaks	Event volume	ℓ/event	–	27.4	–
Shower	b_shower	Event volume	ℓ/event	7.6	59.1	303.0
Shower (Note A)	c_shower	Frequency of use	events/c·d	0.19	0.31	0.68
Toilet	b_toilet flush	Event volume	ℓ/event	8.0	14.3	26.5
Toilet	c_toilet flush	Frequency of use	events/c·d	1.7	3.7	10.3
Washing machine	b_washing machine	Event volume	ℓ/event	60.0	113.6	200.0
Washing machine	c_washing machine	Frequency of use	events/c·d	0.12	0.30	0.63
		End-uses normally located outdoors				
Pool filtering	b_pool filtering	Event volume	ℓ/event	125.0	363.0	600.0
Pool filtering	c_pool filtering	Frequency of use	events/day	0.012	0.024	0.036
		PARAMETERS FOR COMPONENT 2 – OUTDOOR WATER DEMAND				
All, outdoor	p_Vegetation type 1	Monthly pan evaporation	mm/month	–	Note B	–
All, outdoor	R_Vegetation type 1	Monthly rainfall	mm/month	–	Note B	–
All, garden irrigation	f_Vegetation	Garden irrigation factor	dimensionless	0.0	0.5	5.0
Garden irrigation	s_Vegetation type 1	Vegetation surface area	m^2 (Note C)	15%	25%	35%
Garden irrigation	k_Vegetation type 1	Monthly crop factor	dimensionless	–	Note B	–
Garden irrigation	s_Vegetation type 2	Vegetation surface area	m^2 (Note C)	5%	13%	20%
Garden irrigation	k_Vegetation type 2	Monthly crop factor	dimensionless	–	Note B	–
Pool evaporation	f_Pool evaporation	Monthly pool cover factor	dimensionless	–	Note B	–
Pool evaporation	k_Pool evaporation	Evaporation factor	dimensionless	1.0	1.0	1.0

Table 1 | (*continued*)

	Parameter			**Values**		
End-Use	**Notation**	**Description**	**Unit**	**Low**	**Typical**	**High**
All	**n**	**Household size**	**PPH**	**1.0**	**3.0**	**5.0**
Pool evaporation	s_Pool evaporation	Pool surface area	m^2	12.0	35.0	60.0
PARAMETERS FOR COMPONENT 3 – HOT WATER DEMAND						
All, hot water	T_C	Cold water temperature	°C	–	Note B	–
All, hot water	T_H	Hot water temperature	°C	60.0	65.0	70.0
All, hot water	T_B	Blended temperature	°C	34.0	40.2	42.5
PARAMETERS FOR COMPONENT 4 – WASTEWATER FLOW VOLUME						
Bath	u_bath	Return factor	dimensionless	0.0	1.0	1.0
Bathroom basin	u_bathroom basin	Return factor	dimensionless	0.0	1.0	1.0
Dishwasher	u_dishwasher	Return factor	dimensionless	0.0	1.0	1.0
Kitchen sink	u_kitchen sink	Return factor	dimensionless	0.0	1.0	1.0
Leaks	u_leaks	Return factor	dimensionless	0.0	0.9	1.0
Shower	u_shower	Return factor	dimensionless	0.0	1.0	1.0
Toilet	u_toilet large flush	Return factor	dimensionless	0.0	1.0	1.0
Toilet	u_toilet small flush	Return factor	dimensionless	0.0	1.0	1.0
Washing machine	u_washing machine	Return factor	dimensionless	0.0	1.0	1.0
PARAMETERS FOR COMPONENT 5 – WASTEWATER FLOW TDS CONCENTRATION						
All	AADC_potable water	TDS concentration	mg/ℓ	10	164	215
Bath	t_bath	Soluble substance added	mg/event	100	3,900	5,000
Bathroom basin	t_bathroom basin	Soluble substance added	mg/event	500	3,200	3,900
Dishwasher	t_dishwasher	Soluble substance added	mg/event	200	28,800	89,000
Kitchen sink	t_kitchen sink	Soluble substance added	mg/event	100	2,000	2,500
Shower	t_shower	Soluble substance added	mg/event	100	3,900	5,000
Toilet (Note D)	t_toilet – faeces	Soluble substance added	mg/event	500	1,800	3,000
Toilet (Note D)	t_toilet – urine	Soluble substance added	mg/event	9,600	43,700	77,800
Washing machine	t_washing machine	Soluble substance added	mg/event	100	61,000	220,000

Notes:

A. Bath and shower frequencies are evaluated integrally.

B. Monthly value: Monthly climatological parameters are available from other sources.

C. The tabulated values are expressed as % of total stand size for lawn(s); stand size value used for analysis = 1000 m^2.

D. The two values for faeces and urine are added when modelling a toilet.

to calculate the elasticity of an independent parameter, it is necessary to choose a small, arbitrary percentage whereby the parameter value is increased and decreased – that is a point above (D1) and below (D2) the base point respectively for which results could be calculated. Inspection of Equation (7) shows that the exact choice is not critical – the denominator is a constant which "cancels out" the arbitrarily chosen percentage. In this study, a 10% increment was chosen.

The elasticity of the five REUM components with respect to the input parameters are calculated by means of an analysis procedure depicted as a schematic flow diagram in Figure 2. The electronic version of REUM is used to adjust each parameter value and conduct the repetitive analyses. The adjusted inputs and results are used to determine the elasticity around the base point resulting from each model run.

Elasticity is often used to evaluate the impact of a change in demand brought about by TD measures, such as a price increase or pressure reduction. Thus, the E-values presented in Table 2 are useful for comparison to elasticity values published in the literature. Ponder price as an example: Van Zyl *et al.* (2003) provide a summary of price elasticity values from literature. Typical values range from −0.13 to −0.24 for indoor demand (although −0.67 is reported for a high density area in South Africa). For a price elasticity of −0.24 and a price increase of 10%, a user would counter-act the effect in price completely by implementing a BU initiative to reduce the toilet flush frequency or cistern volume by a similar margin of about 10% (the E-values from Table 2 for both these parameters are positive 0.28).

Unfortunately though, the elasticity value does not teach us or the user anything about which of the available BU measures should be the user's primary pursuit in counter-acting the TD change. For this reason, the S-value is more useful and thus forms the crux of the ensuing text.

Calculation of sensitivity

In order to evaluate the sensitivity, low and high values for each parameter are required (refer to Table 1). In the best scenario, enough independent data points would be available to fit a statistical distribution to each input parameter. In such a case, it would be sensible to use (say) a certain fraction of the standard deviation below and above the average. With fewer data points it is considered more appropriate to select a practical low and high value. For the purpose of this investigation, which is a

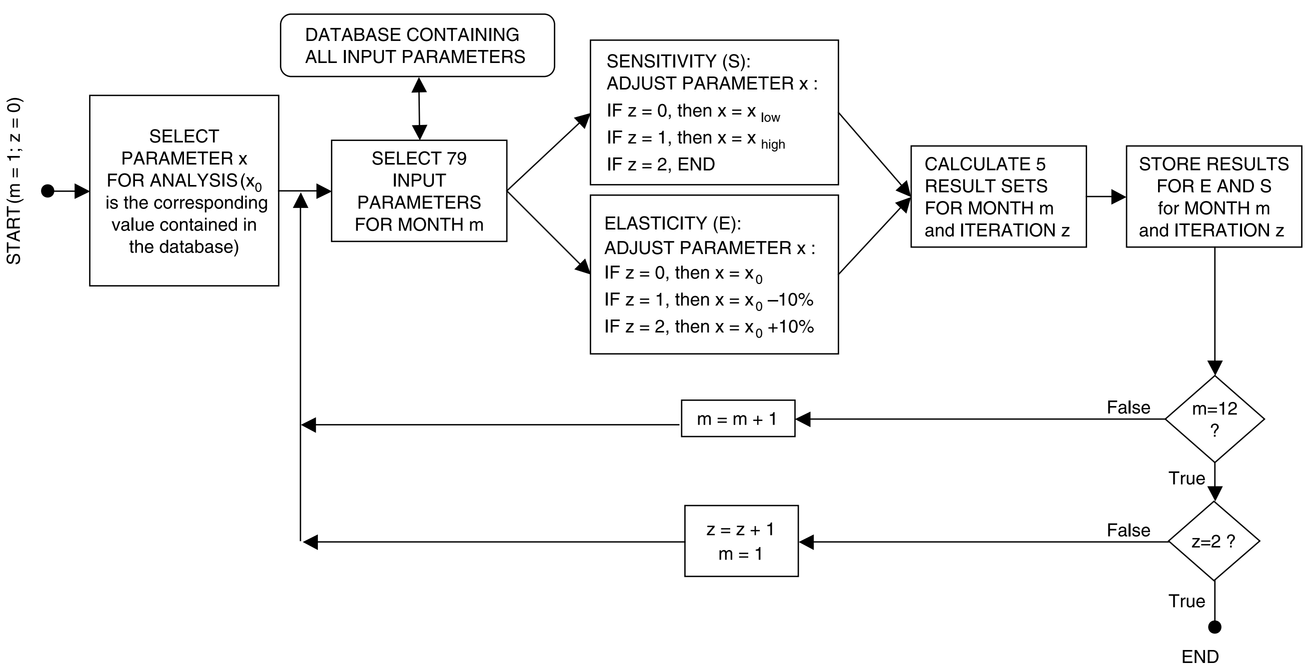

Figure 2 | Flow diagram of REUM function during analysis procedure.

Table 2 | Elasticity (E) and sensitivity (S) for each model component with respect to all input parameters

		$AADD_{indoor}$		$AADD_{outdoor}$		$AADD_{hot}$		$AADF_{wastewater}$		$AADC_{wastewater}$	
Parameter	**Units**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**
n	PPH	1.00	1.04	0.10	0.17	1.00	1.04	1.00	1.04	–	–
b_bath	ℓ/event	0.11	0.19	–	–	0.20	0.34	0.11	0.19	−0.10	−0.16
c_bath	events/c·d	0.11	0.27	–	–	0.20	0.46	0.11	0.27	−0.09	−0.23
b_bathroom basin	ℓ/event	0.07	0.18	–	–	0.14	0.33	0.07	0.19	−0.07	−0.16
c_bathroom basin	events/c·d	0.07	0.01	–	–	0.14	0.02	0.07	0.01	−0.02	0.00
b_dishwasher	ℓ/event	0.03	0.04	–	–	–	–	0.03	0.04	−0.03	−0.03
c_dishwasher	events/c·d	0.03	0.01	–	–	–	–	0.03	0.01	–	–
b_kitchen sink	ℓ/event	0.07	0.23	–	–	0.13	0.41	0.07	0.23	−0.06	−0.20
c_kitchen sink	events/c·d	0.07	0.00	–	–	0.13	0.01	0.07	0.00	−0.05	0.00
b_leaks	ℓ/event	0.15	0.55	–	–	–	–	0.13	0.51	−0.12	−0.44
b_shower	ℓ/event	0.10	0.42	–	–	0.18	0.70	0.10	0.43	−0.09	−0.37
c_shower	events/c·d	0.10	0.21	–	–	0.18	0.37	0.10	0.21	−0.08	−0.17
b_toilet flush	ℓ/event	0.28	0.35	–	–	–	–	0.29	0.35	−0.25	−0.31
c_toilet flush	events/c·d	0.28	0.56	–	–	–	–	0.29	0.57	0.45	0.72
b_washing machine	ℓ/event	0.18	0.22	–	–	0.34	0.39	0.19	0.22	−0.16	−0.19
c_washing machine	events/c·d	0.18	0.30	–	–	0.34	0.54	0.19	0.30	−0.09	−0.14
b_miscl. outdoor	ℓ/event	–	–	0.04	–	–	–	–	–	–	–
b_pool filtering	ℓ/event	–	–	0.06	0.08	–	–	–	–	–	–
c_pool filtering	events/c·d	–	–	0.06	0.06	–	–	–	–	–	–
P	mm/month	–	–	1.59	0.98	–	–	–	–	–	–
R	mm/month	–	–	−0.57	−0.57	–	–	–	–	–	–
f_vegetation 1	dimensionless	–	–	0.51	1.67	–	–	–	–	–	–
s_vegetation 1	M^2	–	–	0.51	0.96	–	–	–	–	–	–
k_vegetation 1	dimensionless	–	–	0.91	0.95	–	–	–	–	–	–
f_vegetation 2	dimensionless	–	–	0.27	1.29	–	–	–	–	–	–
s_vegetation 2	M^2	–	–	0.27	0.59	–	–	–	–	–	–

Table 2 | (*continued*)

		$AADD_{indoor}$		$AADD_{outdoor}$		$AADD_{hot}$		$AADF_{wastewater}$		$AADC_{wastewater}$	
Parameter	**Units**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**
k_vegetation 2	dimensionless	–	–	0.48	0.50	–	–	–	–	–	–
f_pool evaporation	dimensionless	–	–	0.13	0.14	–	–	–	–	–	–
s_pool evaporation	M^2	–	–	0.13	0.50	–	–	–	–	–	–
k_pool evaporation	dimensionless	–	–	0.19	0.08	–	–	–	–	–	–
T_C	°C	–	–	–	–	−0.32	−0.43	–	–	–	–
T_H	°C	–	–	–	–	−1.33	−0.28	–	–	–	–
T_B	°C	–	–	–	–	1.63	0.41	–	–	–	–
u_bath	dimensionless	–	–	–	–	–	–	0.11	0.12	−0.09	−0.09
u_bathroom basin	dimensionless	–	–	–	–	–	–	0.07	0.08	−0.02	−0.02
u_dishwasher	dimensionless	–	–	–	–	–	–	0.03	0.04	–	0.00
u_kitchen sink	dimensionless	–	–	–	–	–	–	0.07	0.08	−0.05	−0.05
u_leaks	dimensionless	–	–	–	–	–	–	0.13	0.16	−0.12	−0.13
u_shower	dimensionless	–	–	–	–	–	–	0.10	0.11	−0.08	−0.09
u_toilet_flush	dimensionless	–	–	–	–	–	–	0.29	0.34	0.45	0.91
u_washing machine	dimensionless	–	–	–	–	–	–	0.19	0.20	−0.09	−0.10
AADC_potable	mg/ℓ	–	–	–	–	–	–	–	–	0.13	0.16
t_bath	mg/event	–	–	–	–	–	–	–	–	0.00	0.01
t_bathroom basin	mg/event	–	–	–	–	–	–	–	–	0.05	0.05
t_dishwasher	mg/event	–	–	–	–	–	–	–	–	0.03	0.09
t_kitchen sink	mg/event	–	–	–	–	–	–	–	–	0.02	0.02
t_shower	mg/event	–	–	–	–	–	–	–	–	0.01	0.01
t_toilet_flush	mg/event	–	–	–	–	–	–	–	–	0.70	1.08
t_washing machine	mg/event	–	–	–	–	–	–	–	–	0.08	0.26

ranking exercise to identify those parameters which deserve closer attention, it does not really matter how the limits are set, as long as they are set consistently for all parameters.

The sensitivity values of the five REUM components are calculated by means of an analysis procedure depicted earlier in Figure 2. The electronic version of REUM is used to conduct the repetitive analyses and determine the sensitivity resulting from each model run. Even though the sensitivity calculation is similar to that for elasticity, there is one critical difference: the adjustment of the parameter value is made in accordance with its likely range, thus taking into account its probable variability and system constraints.

Consider the following illustrative example: a change in the bath volume is investigated – the independent parameter in question is b_{bath}. The low and high values for this parameter are 39 ℓ/event and 189 ℓ/event respectively (from Table 1). The model is populated with typical values for all parameters, except of course b_{bath}. A result set for D_{low} is calculated for each model component described by Equations (1) to (5), thus leading to 5 answers: $AMDD_i = 526$ ℓ/stand·d; $AMDD_o = 419$ ℓ/stand·d; $AMDD_h = 133$ ℓ/stand·d; $AMDW_w = 518$ ℓ/stand·d; $AMDM_s = 1389$ mg/ℓ. This exercise is repeated with the high value of b_{bath}. A second result set D_{high} is calculated: $AMDD_i = 634$ ℓ/stand·d; $AMDD_o = 419$ ℓ/stand·d; $AMDD_h = 187$ ℓ/stand·d; $AMDW_w = 626$ ℓ/stand·d; $AMDM_s = 1178$ mg/ℓ. The scene is now set for the calculation of S for each dependent parameter by making use of Equation (8):

- $S = 0.19$ for indoor demand
- S is zero for outdoor demand (a change in the bath volume has no impact)
- $S = 0.34$ for hot water demand
- $S = 0.19$ for wastewater flow volume
- $S = -0.16$ for the wastewater TDS concentration.

RESULTS FOR ALL MODEL COMPONENTS

The complete results for the elasticity and sensitivity analyses of all five model components, with respect to each parameter, are shown in Table 2 and are discussed in this section with reference to each model component.

Indoor water demand

The indoor demand is notably influenced by the household size (n). Those parameters resulting in relatively high S-values include the toilet flush frequency (c_{toilet}), volume of leaks (b_{leaks}), and shower volume (b_{shower}) in descending order. The list includes mainly parameters with wide range spans (e.g. the shower with a volume range of 8 ℓ/event to 303 ℓ/event). The S- and E-values are positive for all parameters, implying that a reduced parameter value would lead to a reduced indoor demand.

Outdoor water demand

The garden irrigation factors (f) for lawn and garden beds have the highest S-values. The model structure includes garden water demand as a theoretical estimate of vegetation water needs based on evapotranspiration. The garden irrigation factor is included in REUM to explain the relationship between the ideal water requirement and the actual garden water demand (influenced by consumer behaviour). A garden irrigation factor of zero in the model would imply no garden watering by a consumer, while a factor of one would imply watering equal to the theoretical water requirement of the vegetation. A higher factor would imply over-watering, relative to theory.

The garden irrigation factor is varied from zero to five in the sensitivity calculation. This is a relatively large range based on subjective opinion of the authors (a high value of two or three might be more appropriate). The value of five is however justified at this stage due to the fact that little is known about this parameter and it is not easily measured. As an example, change in parameter f between these limits causes the AADD of the baseline property to change from 767 ℓ/stand·d to 2890 ℓ/stand·d (it could be recalled that the property size is 1000m^2). However, analysis of more than 600 000 residential properties' water consumption by Jacobs *et al.* (2004) suggests that 80% of all suburban stands in the size range and geographical region of the baseline property actually use less than 1 255 ℓ/stand·d, implying that the high value chosen for the parameter ($f = 5$, and thus 2890 ℓ/stand·d) results in a high total demand when compared to actual residential properties. In view of engineering conservatism and the uncertainly surrounding this critical parameter, which clearly requires future research focus, the value of five is maintained for the purpose of this ranking exercise.

Three parameters with almost-equal rank follow the garden irrigation factors for lawn and garden beds, namely the pan evaporation (p), lawn surface area ($s_{\text{vegetation type 1}}$) and crop factor of the lawn ($k_{\text{vegetation type 1}}$). The irrigation factors are prominent in view of sensitivity due to the wide range.

The parameter for rainfall is the only one with a negative S-value (and elasticity), implying that an increase in this parameter's value would result in reduced water demand, as would be expected.

Hot water demand

The hot water demand is most sensitive to the household size (n), shower event volume (b_{shower}) and washing machine event frequency ($c_{\text{washing machine}}$), followed by numerous other parameters with lower, yet relatively equal values.

Elasticity calculations suggest that the hot water demand is elastic ($|E| > 1$) with respect to the blended water temperature (T_B) and the hot water temperature (T_H). However, the relatively narrow ranges of the latter parameters limit their sensitivity values. In theory, hot water could be saved by using water at home that is (say) only half a degree centigrade cooler than the baseline value, but it is considered impractical to expect a water user to sense such a temperature change and make a conscious decision in this regard.

The S-values for hot and cold water temperature are negative (as for elasticity), implying that an increase in either of these temperatures would also reduce the hot water demand.

Wastewater flow

Results for the wastewater flow component are similar to those for the indoor demand component, because all but one of the return parameters used in the analysis are equal to one. If return parameters not equal to unity were to be included (e.g. a property with on-site grey water reuse) the results would deviate from those for the indoor component. However, in South Africa on-site grey water reuse is considered uncommon at present.

Wastewater TDS concentration

The three parameters with the highest S-values of wastewater TDS are the mass of soluble substances added at the toilet (t_{toilet}), the toilet return parameter (u_{toilet}) and toilet flush frequency (c_{toilet}).

The sign of each S (and E) value is related to whether that parameter leads to an increase or decrease in the concentration of TDS in the wastewater stream when the value of the parameter is increased. For parameters describing end-uses of which the wastewater has a TDS concentration lower than the total wastewater TDS concentration, S and E are negative, because an increase in the water use at these end-uses reduces the overall TDS concentration. This is the case for most end-uses. In the case of the toilet, an increased flush volume leads to a reduced TDS concentration ($S,E < 0$), but an increased flush frequency leads to an increased overall TDS concentration ($S,E > 0$) – presuming that a pollution event accompanies each flush event. This is because polluted water from the toilet has a higher concentration of TDS than the wastewater for all end-uses combined. The same argument applies to the toilet return parameter.

DISCUSSION

Practical implications

In an attempt to give practical meaning to the results, the focus remains on the sensitivity value, S and intensifies to those parameters with the highest ranks (highest |S| values) and those parameters of which the values could realistically be manipulated by a water user given best available technology not entailing excessive cost (BATNEEC).

Table 3 lists the rank, parameter, S-value, relevant WDM-measures in view of BATNEEC and a comment about the practical manipulability for the top five parameters for each of the five model components.

Parameters with multiple effects

Some parameters in the model impact only one component, while other parameters impact more than one of the model

Table 3 | Results – summary of top 5 parameters for each component

Rank	Parameter	S	Relevant WDM measures	Comment on practical manipulability
Indoor water demand				
1	Household size	1.04	Reduce family size	Long-term planning/contentious issue in many countries
2	Toilet flush frequency	0.56	Reduce flush frequency (e.g. do not flush after each use)	Impacts on habits and health; possible negative perception
3	Leak volume	0.55	Repair "on-site" (plumbing) leaks	Often easy to implement; no habit change
4	Shower event volume	0.42	Reduce shower volume (nozzle flow rate and/or shower duration)	Impacts on habits and health; possible negative perception
5	Toilet flush volume	0.35	Reduce volume of water in toilet cistern	Displacement device is easy to install, but may lead to double flushing; retrofitting a toilet designed to function with low flush volume (or dual flush type) is relatively expensive
Outdoor water demand				
1	Irrigation factor for lawn	1.67	Less lawn irrigation (e.g. water the lawn only in summer)	Easy to implement, but affects habits and could have negative impacts on garden aesthetics
2	Irrigation factor for garden beds	1.29	Less garden bed irrigation	As for lawn
3	Pan evaporation	0.98	Relocation: moving to a geographic region with lower value would reduce demand.	Relocation is a contentious issue. More appropriate measures could include: xeriscaping (e.g. mulching; scheduled irrigation for cooler times of the day; improved soil) and a pool cover – all aimed at reducing evaporation
4	Surface area of lawn	0.96	Reduce lawn area	Xeriscape practices imply a habit change (reduce lawn area in favour of pathways, garden beds, etc.)
5	Crop factor for lawn (grass genotype)	0.95	Change grass genotype (e.g. use kikuyu or buffalo)	Ideal to implement in new garden. For established gardens change is either slow or implies a relatively large expense.
Hot water demand				
1	Household size	1.04	Refer to indoor demand	Refer to indoor demand
2	Shower event volume	0.70	Refer to indoor demand	Refer to indoor demand
3	Washing machine event frequency	0.54	Reduce frequency of washing events; purchase modern washing machine	Impacts on habits; possible negative perception; new washing machine is relatively expensive
4	Bath event frequency	0.46	Reduce the frequency of events or share bath water	Impacts on habits and health; possible negative perception

Table 3 | (*continued*)

Rank	Parameter	S	Relevant WDM measures	Comment on practical manipulability
5	Temperature of cold (supply) water	−0.43	Relocation. Refer to outdoor demand – discussion as per pan evaporation	It is not considered practical or realistic to increase cold water supply temperature, although it is possible.
Wastewater flow volume				
The results for this component are very similar to indoor demand, because most of the return parameters in the model are equal to unity.				
Wastewater TDS concentration				
1	Soluble substances added at toilet	1.08	Mainly due to urine contribution	Manipulation of this value is not considered realistic, as excretion of urine and faeces is driven by bodily function, not choice.
2	Toilet return parameter	0.91	Return less toilet wastewater to the wasteswater system	On-site reuse of some parts (e.g. urine) is possible, but health and practical aspects are a concern.
3	Toilet flush frequency	0.72	Refer to indoor demand	Reduced flow volume implies an increased wastewater TDS, thus increased load on the treatment plant
4	Leak volume	−0.44	Refer to indoor demand	Reduced leak volume is desirable, but would result in higher TDS concentration in wastewater and thus increased load on the treatment plant
5	Shower event volume	−0.37	Refer to indoor demand	Refer to indoor demand for comment

components simultaneously. The most notable parameters with multiple effects include:

- Household size: the result not only underlines the significant effect that household size is known to have on water demand at a residence, but also underlines its impact as a major determinant for hot water demand and wastewater flow volume. For the purpose of this investigation household size is not considered to impact the wastewater TDS component, because all the input parameters describing the mass of soluble substances added at end-uses are measured in per capita terms, thus nullifying the effect of household size on the wastewater TDS concentration in this analysis.
- Toilet flush frequency and toilet flush volume: these parameters impact the indoor water demand, wastewater flow volume and wastewater TDS concentration.
- Washing machine event frequency: this parameter impacts the indoor demand, hot water demand, and both wastewater components.
- Volume of leaks: leaks significantly impact indoor water demand and wastewater flow, but also dilute the concentration of TDS in the wastewater.

End-use contribution to indoor demand

Four end-uses contribute almost 80% to the total indoor demand. These end-uses are the toilet, bath, shower and washing machine. Of these, the bath and shower are used to achieve the same purpose, namely cleaning the body, and the choice of use is driven by individual preference.

Two striking factors are noted when reviewing the literature in conjunction with results from this study. Firstly, review of Table 4 shows that the same four end-uses are

Table 4 | Most significant indoor end-uses reported in literature

Literature reference and description			% Of indoor water demand			
Citation	**Data year**	**Comment**	**Toilet**	**Bath + Shower**	**Washing machine**	**Sub-total**
		INTERNATIONAL				
Billings & Jones 1996	1993	USA, approx. lower values	23	18	18	59
Edwards & Martin 1995	1992	UK, Water Facts	32	17	12	61
Butler & Memon 2006	–	p.8, Sweden, 2001	18	32	13	63
Lauchlan & Dixon 2003	2002	UK, based on Butler (1991)	15	44	7	66
Ball *et al.* 2003	2001	Environment Agency	35	20	12	67
Ball *et al.* 2003	2001	UK; 10 areas, non-peak	30	24	14	68
DeOreo *et al.* 1996	1995	Boulder, CO, USA	26	20	25	71
Edwards & Martin 1995	1993	UK, Cambridgeshire	33	17	21	71
Butler & Memon 2006	–	p.86, UK, 2001	37	21	13	71
DeOreo *et al.* 2001	2000	Seattle, USA, post retrofit	20	29	23	72
DeOreo *et al.* 2001	2000	Seattle, USA, pre retrofit	30	20	23	73
Butler & Memon 2006	–	Figure 1.5, UK, 2000	32	21	21	74
Butler & Memon 2006	–	p.8, Netherlands, 2001	37	26	16	79
Tchobanoglous & Burton 1991	1984	USA	28	30	21	80
Maddaus 1987	1987	USA	28	30	22	80
Baumann *et al.* 1998	1993	USA, CA, Single Family	31	28	22	80
Baumann *et al.* 1998	1993	USA, CA, Multi Family	34	28	19	81
Achttienribbe 1998	1995	Netherlands	29	35	21	85
Billings & Jones 1996	1993	USA, approx. upper values	38	25	25	88
		SOUTH AFRICA				
Garlipp 1979	1976	Cape Town	27	42	15	84
Schutte & Pretorius 1997	–	High-income (suburban)	20	61	4	85
Garlipp 1979	1976	Durban	26	49	11	85
Jacobs *et al.* 2006	2004	Cape Town, normal use	34	30	21	85
Jacobs *et al.* 2006	2004	Cape Town, restrictions	38	32	17	86
Garlipp 1979	1976	Gauteng (Johannesburg)	31	46	9	87
Jacobs *et al.* 2006	2004	Cape Town, RDP [A]	73	19	0	92
Veck & Bill 2000	1998	Alberton, 150 homes	17	74	3	94

Notes:
A) High density, low-income dwellings named after the Reconstruction and Development Program (RDP).

responsible for the most significant contribution to indoor demand in all sources reviewed. Secondly, the combined contribution is relatively constant at between 70% and 80% for international locations and about 85% for South Africa, despite great variability in study locations and dwelling types.

Most of the other studies are empirical in nature, implying a restraint in future application when modelling WDM initiatives' impact on water quantity and quality. This study, making use of an entirely mathematical procedure, confirms the empirical results presented in Table 4. At an increased resolution this research identifies which specific parameters describing each end-use have the most notable impact on the model result for each model component. It is also possible to model hitherto unknown WDM measures in future with the model by adjusting individual model parameters.

Water saving potential

Knowledge of the water saving achieved per end-use could be used as an indication of which end-uses might have a relatively larger impact on water demand than others. Model parameters describing end-uses with the most significant savings are expected to be those with relatively high rankings. The end-uses identified as being significant in their contribution to water demand often also contribute most to water savings – the garden, toilet, bath, shower, washing machine and leaks. Reported water savings per end-use, including hot water savings reported in one paper, are presented in Table 5.

The most notable water savings in indoor demand are reported for the toilet, washing machine, bath, shower and repairing leaks, while the end-uses with the most significant impact on hot water use are the bath, washing machine and leaks. The reported savings for the shower are the most variable.

Turning to outdoor uses, Billings & Jones (1996) report a saving of up to 50% for xeriscape landscaping. This is reinforced by later findings: Hunt *et al.* (1998) also suggest that xeriscape gardens may reduce total water demand of a property by as much as 50%. In South Africa Jacobs & Haarhoff (2004*b*) report a theoretical reduction of between 9% and 39% for xeriscaping a typical suburban property. The saving within this range is influenced by the state of the garden prior to implementation of xeriscape measures and how severely xeriscaping is modelled. Actual water reduction of up to 40% was reported by Jacobs *et al.* (2007) for residential users in the City of Cape Town, where mainly garden water use was targeted during water restrictions. Their work comprises analysis of metered monthly water use and includes about half a million users' water meter records prior to and after implementation of restrictions.

The predominant nature of outdoor use with regards to saving potential is well-known with first reports recorded more than four decades ago. However, this research provides penetrating insight into why this is so. It provides a better understanding of water use characteristics and penetrates to identify specific drivers behind demand and related savings. The most notable effect is found in the garden irrigation factor, f, which has the largest S-value (refer to Table 2). Thus, it would be more effective to reduce this factor than to reduce the lawn area or change the vegetation type, for example.

This explains why some TD measures in WDM programmes addressing the ratio of actual demand to theoretical demand are found to be very effective. The so-called "tuna can plan" promoted by the Colorado Springs Utilities (www.csu.org) is such an example. It was a campaign to promote the use of a tuna can to measure the actual water irrigated onto a lawn. The consumer could then compare the actual irrigation (measured by the depth of water in the 25 mm deep tuna can) with the lawn water requirement of 25 mm per week (determined for that study area in summer). In essence this plan was addressing parameter f and was giving the user a practical and cost-effective way to measure the water application in relation to theoretical vegetation water needs, and in so doing f would approach unity. In the extreme case of severe water restrictions, as discussed by Jacobs *et al.* (2007), f would approach zero implying no water use for garden irrigation.

Wastewater flow by end-use

Wastewater flow is dependent on the water demand of a particular end-use and the fraction of it returned to the wastewater system. Literature on the topic is in broad agreement with results from this study. Simpson (1991) reports on a toilet retrofit programme and its impact on the wastewater flow in two townships in South Africa, but does

Table 5 | Selected water savings reported in literature

Description	Ref. 1 % Saving	Ref. 2 Expected saving	Ref. 3 Pre-retrofit, post-retrofit and water saving: Indoor use (l/c/d) Pre	Post	Saved	Hot water use (l/c/d) Pre	Post	Saved
Bath	24%	not reported	14.0	10.2	3.8	15.9	9.5	6.4
Washing machine	69%	not reported	56.0	34.8	21.2	14.8	5.7	9.1
Dishwasher	50%	not reported	5.3	4.5	0.8	3.4	3.8	−0.4
Tap	not reported	1,9 l/c/d	34.8	30.3	4.5	32.6	29.1	3.5
Kitchen sink	72%	not reported			not reported			
Leak	not reported	15,5 l/c/d (toilet only)	24.6	8.3	16.3	4.5	3.0	1.5
Shower	52%	27,2 – 37,5 l/c/d	34.1	32.9	1.2	23.8	26.5	−2.7
Toilet (incl. retrofit)	76%	59,1 – 68,1 l/c/d	71.2	29.9	41.3	0.0	0.0	0.0
Toilet valve retrofit	not reported	7,6 l/c/d			not reported			
Toilet displacement bag	not reported	10,6 l/c/d						
Drip irrigation system retrofit	100%	20% of outdoor use						
Soil preparation & mulching		15% of outdoor use						
Xeriscape landscaping		50% of outdoor use						
Evaporation reduction		30% of outdoor use						
Moisture sensors		40% of outdoor use						

Notes
Ref. 1: Butler & Memon (2006)
Ref. 2: Billings & Jones (1996)
Ref. 3: DeOreo *et al.* (2001).

not present specific results of changes in flow in relation to water demand. Zeisel & Nolde (1995) report that, on average, 56% of the total water demand for a West-Berlin dwelling in 1990 ended as wastewater flow generated by the toilet, dish washing and food preparation, with lack of detail regarding the specific contributions by each end-use. However, both studies reported on flow generated by the toilet, suggesting that the toilet as end-use is significant in this regard, as reported in this study.

Butler (1991) as well as Lauchlan & Dixon (2003) report on the modelling of water discharges per end-use. The latter authors include houses with conventional and low water use appliances in the study. In each case the toilet, washing machine, bath and shower are reported to have the most significant impact on wastewater flow volume.

OVERVIEW

Household size

The household size is justifiably entwined in the REUM model structure. Not surprisingly, it is found to have the most significant impact on the end-use model result for the indoor water demand and wastewater flow components. It also has the most significant impact on the hot water demand component. A reduction in this parameter's value has a substantial impact on the model result for three of the five components.

Based solely on the model result a reduction in household size has the most notable impact on the water demand of a residential property and also on the hot water demand and wastewater flow. However, substantial evidence (e.g. Edwards & Martin 1995; Jacobs *et al.* 2007) exists to show that smaller household sizes are associated with increased per capita water consumption. A reduction in household size is thus not effective in reducing demand. Also, it might seem to suggest that population would have to be controlled by managing either the total numbers or where people live, or both – matters widely regarded as contentious from a socio-political viewpoint. Attempting to manage household size could be viewed as a dilemma rather than a step towards successful WDM. What is critical is that a thorough knowledge of the household size should be obtained with accuracy and care when modelling demand in this manner.

Toilet

The toilet is one of the focus points in view of BU measures and for improving efficiency in indoor water demand in those locations where inefficient toilets are still in use. In South Africa a nine litre flush volume is often considered "low" in suburban houses. About 80% of toilet sales in the UK are reported to be of the dual flush type (Grant & Howarth 2003), but dual flush toilets are not common in South Africa and are often not stocked in retail stores (recent changes in this regard are encouraging). This knowledge, in addition to the relative importance of the toilet flush volume and frequency parameters, suggests that use of dual flush toilets could hold significant promise for future improvements in efficiency of water use in South African suburbs. However, the toilet also leads to the most substantial increase in wastewater TDS concentration when the water demand, and thus wastewater flow, is reduced.

Leaks

Leaks have been reported to be surprisingly common. DeOreo *et al.* (1996) reported the most common causes for leaks to be leaking toilet flap valves and leaks in irrigation systems, while DeOreo *et al.* (2001) reported leaking toilet flap valves as the main cause for leaks. Leaking water from the toilet flows directly into the wastewater system, thus also impacting the result of the two wastewater components.

Water leaks are – obviously – a complete and direct waste of water and should receive priority in the drive to use water more efficiently.

CONCLUSION

Two end-uses are singled out due to their significant impact on the modelled result for water demand in relation to other end-uses: lawn irrigation and toilet use. In addition, water at these end-uses is not needed at potable standards. Improved, practical techniques for water supply and reuse with regards to garden watering and toilet flushing should be sought in addition to improved efficiency of use. This would lead to a reduced demand and, in the latter case, also to more saline wastewater.

Some of the parameters identified in this research with high ranks are linked to BU WDM measures. Some imply physical actions whereby efficiency of water use could be improved without changing consumer behaviour. These include repairing leaks, reduction of toilet flush volume, and application of some xeriscape practices (e.g. soil improvement to reduce the volume of water needed by plants; mulching to reduce water loss by evaporation; use of native plants with a lower crop factor than alien species; timing irrigation schedules to match times of the day with reduced evaporation loss). Other high ranking parameters are linked to changes in human habits, with potentially controversial social effects if encouraged (e.g. a reduction in toilet flush frequency).

The predominant nature of outdoor use with regards to demand and potential for water saving is underlined by this research. However, parameters describing outdoor use are not implicated as determinants for wastewater flow quantity or quality. Wastewater flow would be reduced and TDS concentration increased mainly by changes in the volume of water generated by the toilet and a reduction in leaks into the wastewater system.

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First received 17 August 2006; accepted in revised form 4 July 2007