

# END-USE ESTIMATES OF WATER DEMAND WITHIN CERTAIN RESIDENTIAL CATEGORIES IN THE CITY OF JOHANNESBURG

H Jacobs<sup>1</sup>, AA Ilemobade<sup>2</sup>, BE Botha<sup>1</sup>

<sup>1</sup> Department of Civil Eng., Stellenbosch University. Private Bag X1, Matieland, 7602, South Africa

<sup>2</sup> School of Civil & Environmental Engineering, University of the Witwatersrand, Johannesburg.

Private Bag 3, WITS, 2050, South Africa

<sup>2</sup>adesola.ilemobade@wits.ac.za

## ABSTRACT

*Increasing drought in many South African communities is driving the need to accurately estimate the end-uses of water within different categories of water users and as a consequence, to realistically determine by how much water use can be reduced. In some water catchments, the accurate estimation of different end-uses is urgently needed given the recent limitations put in place to curtail water. This study, which is part of a larger study commissioned by Johannesburg Water, provides theoretical estimates, using REUM, for end-uses of water for several middle-income homes in a study area served by Johannesburg Water. For indoor end-use, 1, 2, 3 and 4 people per household were modelled and for outdoor end-use, specifically garden irrigation, two cases were modelled i.e. plot sizes of 500m<sup>2</sup> (15% irrigated area) and 1500m<sup>2</sup> (35% irrigated area).*

*For indoor end-use, parameters that are noted to be quite variable include: shower event volume (shower flow rate and duration); shower- and bath frequency; washing machine event frequency and toilet flush frequency. The results validate earlier reports i.e. that the largest 4 end-uses (i.e. toilet, bath-shower and washing machine) contribute 81.5% to total indoor water use, with the shower being the most notable indoor end-use. Outdoor water use for the 1500m<sup>2</sup> plot (35% irrigated area) is notably higher in summer (i.e. December to February), when rainfall is prevalent, than indoor use. This large water requirement is explained by the difference between the evaporation rate and rainfall in the summer months. On the other hand, for the 500m<sup>2</sup> plot (15% irrigated area), the garden irrigation requirement is notably less than indoor end-use, irrespective of household size. At this stage of the project, it is apparent that Water Demand Management measures should target the identified notable indoor end-uses (i.e. toilet, shower, bath and washing machine) for relatively smaller properties. For larger properties however, the focus should be on reducing garden irrigation.*

**Keywords:** Indoor, outdoor, end-use

## 1 BACKGROUND: RESIDENTIAL END-USES

End-uses of water are the building blocks of the residential water demand pattern [1]. Residential water end-uses can be categorised into indoor and outdoor use. Previous studies suggest outdoor use to be seasonal whilst indoor use is not [2]. Typical indoor end-uses include: bath, dishwasher, shower, taps, toilet, and washing machine. Typical outdoor end-uses include car washing, garden irrigation, swimming pool and other miscellaneous uses.

### 1.1 Indoor end-uses

Table 1 provides a review of end-use contribution to total indoor demand, as recorded in various earlier studies [3]. The toilet, bath, shower and washing machine contribute most notably (about 75-85%) to total indoor water demand in all studies. The bath and shower share the same purpose - for

personal cleaning - and could be viewed as one end-use. For example, a person would choose between a bath or shower to complete a single event, not both.

Table 1. Contribution by end-uses to indoor demand [3]

Reference	Study area	End-use share (%)						
		Toilet	Shower	Washing machine	Tap	Dishwasher	Bath	Total indoor
Edwards & Martin (1995)	UK, 100 homes	34.0	4.1	21.6	25.8	1.0	13.4	100.0
DeOreo <i>et al.</i> (1996)	USA, 16 homes	29.3	19.5	28.2	16.7	3.4	2.9	100.0
Mayer <i>et al.</i> (1999)	USA/Canada, 1,188 homes	31.9	19.9	25.7	18.7	1.8	2.0	100.0
DeOreo <i>et al.</i> (2001) Pre-retrofit	USA, 37 homes	33.0	15.9	26.1	16.1	2.5	6.5	100.0
DeOreo <i>et al.</i> (2001) Post-retrofit	USA, 37 homes	21.0	23.0	24.4	21.2	3.2	7.1	100.0
Loh & Coghlan (2003)	Australia, 120 homes	22.0	34.1	26.8	17.1	-	-	100.0
Mayer <i>et al.</i> (2003) Pre-retrofit	USA, 33 homes	33.0	19.9	23.0	17.4	1.7	5.0	100.0
Mayer <i>et al.</i> (2003) Post-retrofit	USA, 33 homes	22.5	24.6	20.2	24.1	2.1	6.4	100.0
Roberts (2005)	Australia, 100 homes	19.3	31.5	27.1	17.7	1.7	2.6	100.0
Heinrich (2007)	New Zealand, 12 homes	19.5	39.4	23.7	13.6	1.3	2.5	100.0
Willis <i>et al.</i> (2000)	Australia, 151 homes	15.4	36.4	22.0	19.8	1.6	4.7	100.0
Scheepers & Jacobs (2014)		19.8	18.4	36.9	10.0	4.7	10.3	100.0
This study								

A summary of indoor use in South Africa is presented in Table 2 [4], with a focus on only the most notable end-uses i.e. toilet, bath, shower and washing machine. Between 84% and 94% of indoor water use can be ascribed to these end-uses in all but one of the studies. It is obvious therefore, that further investigation into end-uses of water indoors, and also future water demand management and water conservation efforts, would produce the best results if the focus is placed on these end-uses.

Table 2. Contribution by end-uses to indoor demand from South African studies [4]

Literature Reference and Description			% Of Indoor Water Demand			
Citation <sup>A</sup>	Data Year	Comment	Toilet	Bath + Shower	Wash Machine	Sub-Total
Malan et al 1983	-	Detail not specified	34	21	11	<b>66</b>
Garlipp 1979	1976	Cape Town	27	42	15	<b>84</b>
Schutte & Pretorius 1997	-	High-income (suburban)	20	61	4	<b>85</b>
Malan et al 1983	-	General / Typical	30	41	14	<b>85</b>
Garlipp 1979	1976	Durban	26	49	11	<b>85</b>
Jacobs et al 2006	2004	Cape Town, normal use	34	30	21	<b>85</b>
Jacobs et al 2006	2004	Cape Town, restrictions	38	32	17	<b>86</b>
Garlipp 1979	1976	Gauteng (Johannesburg)	31	46	9	<b>87</b>
Malan et al 1983	-	Detail not specified	42	32	14	<b>88</b>
Hermanus Mun. 1998	1997	Municipality, estimate	45	31	15	<b>90</b>
Jacobs et al 2006	2004	Cape Town, RDP <sup>B</sup>	73	19	-	<b>92</b>
Veck and Bill 2000	1998	Alberton. 150 homes	17	74	3	<b>94</b>

## 1.2 Outdoor end-uses, particularly garden irrigation

A significant portion of household water demand is attributed to outdoor use [5], mainly garden irrigation. Garden irrigation contributes most to outdoor water demand if the garden is irrigated [6].

The main factors influencing outdoor water use are: garden size [5], vegetation type, and climate [7]. The method of garden irrigation contributes to the duration of garden irrigation events, and thus, the total irrigation volume. Typical residential irrigation methods include buckets or watering cans, hand held hoses, manual sprinklers and automatic sprinkler systems.

Table 3 [4] lists a range of reported values representing the percentage of total household water demand used for garden irrigation purposes. As can be seen, the percentage of total water demand

used for irrigation purposes vary significantly from one study to the next. Literature thus shows that garden water demand cannot be easily predicted.

*Table 3. Review of garden irrigation demand as percentage of total demand [4]*

Literature reference	Location	% irrigation of total water demand (over study period)
Willis et al. (2011)	Australia	10.8 – 18.0
Beal et al. (2011)	Australia	5.0
Heinrich (2007)	New Zealand	8.3 – 21.0
Jacobs et al. (2006)	South Africa	23.0 – 37.0
Roberts (2005); Roberts (2004)	Australia	17.5 – 28.0
Loh and Coghlan (2003)	Australia	54.0
Wasowski (2001)	United States of America	40.0 – 60.0
Allen (2000)	United States of America	59.2
Parsons (2000)	South Africa	30.0
Veck and Bill (2000)	South Africa	0.0 – 69.5
Mayer and DeOreo (1999)	United States of America	58.7
Dietemann (1998)	United States of America	58.0
Van der Linde (1998)	South Africa	35.0
De Oreo et al. (1996)	United States of America	77.6
DWAF (1994)	South Africa	35.0
Granger (1992)	South Africa	50.0
Garlipp (1978)	South Africa	73.0

## 2 STUDY MOTIVATION AND OBJECTIVES

Increasing drought in many South African communities is driving the need to accurately estimate the end-uses of water within different categories of water users and as a consequence, to realistically determine by how much water use can be reduced. In some water catchments, the accurate estimation of different end-uses is urgently needed given the recent limitations (currently, a 15% curtailment on urban water use) put in place by the National Department of Water and Sanitation [8].

In response to the above, Johannesburg Water, JW (the entity that supplies potable water to the Greater Johannesburg Metropolitan Area) introduced level-2 water restrictions (in November 2015) and water restriction tariffs (in September 2016) [9]. Level-2 water restrictions, according to section 44 (3) of the City of Johannesburg's Water Services Bylaw, states that all consumers are compelled: (a) not to irrigate their gardens with municipal water between 06h00 and 18h00 every day. Only hand held hosepipes or buckets/watering cans are allowed for irrigation outside these hours; (b) not to fill swimming pools with municipal water; and (c) not to wash cars and clean paved areas with a hosepipe using municipal water.

The water restriction tariffs which were imposed in a stepped manner introduce a 10% tariff increase on consumption between 20 and 30 kilolitres a month, a 20% tariff increase on consumption between 30 and 40 kilolitres a month and a 30% tariff increase on consumption above 40 kilolitres a month.

Against this backdrop, JW commissioned a study whose objectives are to firstly, provide the client with theoretical estimates for end-uses of water for a variety of homes in the area served by JW; secondly, to conduct empirical analyses of actual water use recorded by JW prior to (and during) the project for  $\pm 65$  homes; and thirdly, to set up an end-use model and calibrate it against actual end-uses and consumer survey inputs. A number of specific WC/WDM measures will subsequently be modelled to assess potential water savings. This paper addresses the first objective.

### **3 METHODS FOR QUANTIFYING END-USES**

#### **3.1 Direct end-use measurement**

This method, which is the most efficient method for quantifying end-use, uses water meters to measure water consumption at each end-use. The research conducted by [10] installed 14 water meters at various appliances in each of the 100 households sampled. The study was conducted in the United Kingdom, with flow measurements recorded every 15 seconds. The cost of installing flowmeters at each end-use point in a household is relatively high. Homeowners are also unlikely to accept the plumbing complexities involved with installation of meters at each end-use.

#### **3.2 Flow trace analysis - flows recorded via consumer meters**

Flow trace analysis can be used to predict end-use demand based on a time series of consumer flow rates. Accurate flow metering (using a smart meter) at a high temporal resolution, at the point of supply to a household, is essential. The method involves measuring the flow of water from consumer supply meters, and then using software such as Trace Wizard, to determine the end-use. The software identifies a unique flow pattern for every end-use based on the time series data. The idea is that every end-use in a home has a unique “finger print” in terms of flow rate and duration, that could be used to identify unique end-use events. A notable study in this respect is [11].

#### **3.3 Surveys**

Another method to estimate residential water demand is from data collected through consumer end-use surveys. Surveys could be in the form of questionnaires administered to homeowners or interviews conducted through site visits. A study that utilised this method is [12]. Surveys are valuable data collection instruments when used to complement logged water use data.

#### **3.4 Temperature data loggers**

Temperature loggers were employed by [13] to measure the variation in temperature of outlet pipes to determine groundwater pumping duration in rural areas in India. This method has also been used to identify durations of flow events [14] and [15]. The principle is to identify events based on the difference between the recorded end-use outlet temperature (e.g. outlet pipe of a garden borehole) and some baseline temperature, generally recorded simultaneously as control. The temperature loggers are typically small in size (18 mm diameter), rugged, accurate, and also very cost effective.

#### **3.5 Acoustic, pressure and other detection methods**

A number of studies have proposed indirect approaches using, for example, microphones, pressure sensors and accelerometers, for sensing water usage at a fixture. A recent study [16] conducted field tests in Malawi where outdoor taps at 10 homes were fitted with small-sized microphones and digital sound recorders. Sound files recorded over a one-month period were used in the analysis. Tap use events were identified based on visually recognizable waveforms and spectrogram features. The performance of an automatic detection algorithm in identifying event start and end times was reasonable, showing that water use events could be detected at precision and recall rates of at least

80% under suitable conditions. Indirect flow sensing approaches are attractive for investigating water use event timing, because of the relatively lower cost when compared to conventional or smart water meters. Plumbing changes are not required as the recorder can be mounted on any exposed pipe section near the fixture of interest.

## 4 END-USE MODELS AND SOFTWARE

The simulation of water demand end-use model (SIMDEUM) was presented by [17] for theoretical end-use analysis. SIMDEUM simulates water demand patterns based on end-use models that are populated using statistical information of users and end-uses. In this study, 3200 residents were surveyed to obtain input values. The survey results were used to define probability distributions for multiple end-uses, namely: toilet, shower, washing machine, dishwasher, kitchen tap, bathroom tap, bath and outside tap.

The residential end-use model (REUM) [6] was developed for theoretical end-use analysis. REUM calculates the household water demand based on fixed monthly inputs. Both indoor and outdoor end-uses are modelled, namely: bath, bathroom basin, dishwasher, kitchen sink, leaks, miscellaneous indoor, shower, toilet flush (large), toilet flush (small), washing machine, garden irrigation, miscellaneous outdoor, and pool evaporation. The monthly inputs include the number of people per household (PPH), a presence parameter to tell if an end-use is present or not, the event volume and frequency of use. A total of 111 parameters are needed to populate REUM and model water use in any month. REUM was programmed using Visual Basic for Application. In this paper, REUM was employed to estimate end-uses of water within households.

Flow trace analysis software products, such as Trace Wizard and Identiflow, require time series data from water meters to categorise household end-uses based on their unique flow patterns. Flow trace analysis software is able to identify simultaneous events due to its unique parameters for each end-use. The main disadvantage of Trace Wizard is that human interaction and manual reclassifications are needed to analyse the collected data [18], and in addition, the accuracy depends on the water meter type and logging frequency. Trace Wizard is not able to distinguish between specific end-uses such as the bathroom tap, kitchen tap, or laundry tap, or between end-uses with similar water flow characteristics, such as showers and bathtubs [18].

Intelligent pattern recognition models are able to automatically categorise different water end-uses by matching patterns. These models (e.g. [19]) use an integrated approach, combining high resolution water meters, remote data transfer loggers, household water appliance audits and self-reported household water-use diaries.

## 5. THEORETICAL ESTIMATES OF END-USE

### 5.1 Selection of different types of homes

The following types of homes were modelled:

- a) Indoor water use: Household (hh) size has been noted to be the most notable parameter influencing indoor water use. Middle-income households within the identified study area covered by JW typically range from 1 to 4 PPH. In the analysis therefore, household size of 1, 2, 3 and 4 PPH was used.
- b) Outdoor water use: Plot size and irrigated area are notable factors contributing to outdoor water use. In this paper, two different plot sizes (with the irrigated area per plot expressed as a percentage in brackets) were considered, namely Property A - 500m<sup>2</sup> (15% irrigated) and Property B - 1500m<sup>2</sup> (35% irrigated). The two cases could be viewed as typical low-outdoor

water use scenario (500m<sup>2</sup>) and typical high outdoor water use scenario (1500m<sup>2</sup>) respectively. Rainfall and evaporation also contribute notably to the theoretical outdoor water use and reliable information for these parameters was obtained from a nearby weather station.

## 5.2 Indoor use

### Indoor model input parameters

The input parameter values for the indoor end-uses are presented in Table 4. The values are quite typical of middle-income households in the JW area. The per capita water use, and the frequency of use, are linearly related to household size in this modelling exercise.

Table 4. Input parameter values for indoor end-use modelling.

Input values for indoor end-use modelling suitable for modelling study site homes			
End Use	Unit	Value	Comment
Household size	PPH	1-4	Integer value varied between 1 and 4 PPH
Bath	L/event	80.0	Physical inspection; 10 bathtubs; 140mm water depth for average tub size (80-85L)
Bath <sup>A</sup>	events/c/d	0.25	Note: combine shower and bath event frequency
Bathroom basin	L/event	4.0	Approx value from various other studies
Bathroom basin	events/c/d	3.4	Mean number of uses per day; typical published value
Dishwasher	L/event	35.0	Various studies report 30 to 40 L/event; approx value used here
Dishwasher <sup>B</sup>	events/c/d	0.20	Notable range, from 0.17 up to 1.0 reported by various literature sources
Kitchen sink	L/event	6.0	Typical volume per use; measurement of typical basin capacity; similar to literature
Kitchen sink <sup>B</sup>	events/c/d	2.0	Mean number of uses per day from various studies
Miscl. indoor	L/event	0	Assumed to be zero - would be assessed during further calibration
Miscl. indoor	events/c/d	0	Assumed to be zero - would be assessed during further calibration
Shower	L/event	80.0	Flow rate 10L/min@10min duration = 100L/event; used $\pm 9$ L/min @ $\pm 9$ min duration <sup>C</sup>
Shower <sup>A</sup>	events/c/d	1.0	Note: combine shower and bath event frequency
Toilet	L/event	9.0	Notable range: 9L/flush typical in South Africa for "newer" toilets
Toilet	events/c/d	3.0	Flushing at home only; Survey 1500 households in Rand Water supply area 3.7 PPH
Washing machine	L/event	80.0	Notable variation between 60-160 L/event depending on machine type
Washing machine	events/c/d	0.2	Notable variation: 0.08 (Rand Water, 2001); 0.19 (Butler 1991); 1.04 (Patterson 1998)

Notes:

A. The bath and shower event frequency is inter-related.

B. The dishwashing machine and kitchen sink event frequency are inter-related (homes with no DW would have more kitchen sink events).

C. The shower volumes and durations of 700+ events were analysed by the research team as part of a recent student study.

### Indoor end-use results

The values listed in Table 4 were input into REUM. Table 5 presents results of indoor end-uses in typical middle-income households and also shows corresponding monthly water use.

Water use is about 5 kL per month per person, increasing to 21kL per month for a 4-person household. Parameters that are noted to be quite variable include: shower event volume (shower flow rate and duration); shower- and bath frequency; washing machine event frequency and toilet flush frequency. The results are in line with earlier reports i.e. that the largest 4 end-uses (i.e. toilet, bath-shower and washing machine) contribute 81.5% to the total indoor water use. As can be noted, the shower is by far the most notable indoor end-use. The washing machine was modelled with a relatively low use of 80 L/event, which is typical of modern machines. However, top loader washing machines may use almost double that volume.

Table 5. Results of indoor end-use modelling

End-use model results: Jhb Water indoor end-uses						
Household size	(PPH)	1	2	3	4	Share (%)
End-use (eu)	Unit	Volume used (L)				
Bath <sup>A</sup>	(L/eu-day)	20	40	60	80	11.4
Bathroom basin	(L/eu-day)	14	27	41	54	7.7
Dishwasher	(L/eu-day)	7	14	21	28	4.0
Kitchen sink	(L/eu-day)	12	24	36	48	6.8
Miscl. indoor	(L/eu-day)	0	0	0	0	0.0
Shower <sup>A</sup>	(L/eu-day)	80	160	240	320	45.6
Toilet	(L/eu-day)	27	54	81	108	15.4
Washing machine	(L/eu-day)	16	32	48	64	9.1
Total indoor use	(L/hh-day)	176	351	527	702	100.0
Corresponding monthly modelled indoor water use:						
Monthly use	(kL/month)	5	11	16	21	

Notes:

A. Shower event frequency is higher than the bath event frequency in this case.

### 5.3 Outdoor use

#### Weather and related parameters

Three input parameters pertaining to the outdoor end-use model vary monthly, namely the rainfall, evaporation and crop factor. Weather station A2E00110 with  $\pm 90$  years of records was employed in this exercise (Table 6).

Table 6. Summary of A2E00110 weather station data ( $\pm 90$  years) near the study site

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Rainfall	59.7	107.9	113.8	125.5	94.4	85.6	44.9	18.4	8.3	4.9	5.6	15.0	684.0
Evaporation	189.3	189.2	197.0	187.5	162.1	149.0	115.9	93.0	73.0	82.5	115.8	157.1	1711.0

Crop factor describes the evapotranspiration of the vegetation genotype in relation to pan evaporation. The Crop factor for Kikuyu, considered to be most applicable for lawns in South Africa, was used in this study (Table 7).

Table 7. Summary of monthly Kikuyu Crop factor values

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Crop factor	0.47	0.61	0.68	0.68	0.68	0.60	0.47	0.31	0.22	0.22	0.22	0.30

#### Other outdoor parameters

The two different plot sizes considered were linked to two irrigation coverage areas, namely Property A - 500m<sup>2</sup> (with 15% irrigated area) and Property B - 1500m<sup>2</sup> (with 35% irrigated area). The two irrigation areas are thus calculated as 75m<sup>2</sup> (low water use scenario) and 525m<sup>2</sup> (high water use scenario). Table 8 provides a summary of all outdoor parameters used in the model.

Table 8. Summary of all input values for outdoor end-use modelling

Parameters for outdoor end-use modelling (Garden irrigation)			
Parameter	Unit	Value	Description
Pan evaporation	mm/month	Monthly <sup>A</sup>	A-Pan evaporation
Rainfall	mm/month	Monthly <sup>A</sup>	Actual rainfall (effective rainfall, $r$ , is calculated in REUM)
Garden irrigation factor	dimensionless	1	Garden irrigation factor ("system efficiency")
Garden irrigation area	m <sup>2</sup>	Varies <sup>B</sup>	Surface area of vegetation: 75m <sup>2</sup> (low) and 525m <sup>2</sup> (high)
Garden crop factor	dimensionless	Monthly <sup>A</sup>	Crop factor - a constant for certain vegetation type

Notes:

A. The input values for all parameters that vary monthly are presented separately, per month

B. Refer to the text for discussion on different garden irrigation areas selected for modelling in this study.

### Outdoor end-use results - garden irrigation

The inputs listed in Tables 6, 7 and 8 were analysed using REUM. Results are presented in Table 9 for the two selected irrigation areas along with corresponding monthly water use for garden irrigation.

Table 9. Results of outdoor end-use modelling - garden irrigation

Results of outdoor end-use modelling: Garden irrigation													
Property	Irrigated area (m <sup>2</sup> )	Water use (L/day)											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
A: 500m <sup>2</sup>	75	115	122	158	128	124	85	48	25	19	33	49	78
B: 1500m <sup>2</sup>	525	807	852	1107	894	867	592	339	175	133	228	342	544
Property	Irrigated area (m <sup>2</sup> )	Water use (kL/month)											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
A: 500m <sup>2</sup>	75	3.6	3.7	4.9	4.0	3.5	2.6	1.5	0.8	0.6	1.0	1.5	2.3
B: 1500m <sup>2</sup>	525	25.0	25.6	34.3	27.7	24.3	18.4	10.2	5.4	4.0	7.1	10.6	16.3

In line with other findings, outdoor water use for relatively large properties with irrigated gardens is notably higher in summer (December to February), when rainfall is prevalent, than indoor use. This large water requirement is explained by the difference between the evaporation rate and rainfall in the summer months. Johannesburg has a relatively high evaporation with average evaporation of 1711mm/yr recorded at station AE00110. Consider 1m<sup>2</sup> of grass and the difference of 83mm/month for December (refer to Table 6) between evaporation and rainfall: the nett evaporation from open water would thus be 83L/m<sup>2</sup> per month. Also, not all rainfall is effective. REUM uses an equation to transform actual rainfall to effective rainfall, thus notably reducing the rainfall volume that infiltrates the soil. Finally, a crop factor of 0.68 for grass in December (from Table 7) is introduced, leading to a water requirement for grass of  $(0.68)(83) = 56$  L/m<sup>2</sup> per month, when disregarding effective rainfall. This is about 2 L/m<sup>2</sup> per summer day, on average. The theoretical requirement to irrigate Property A - 500m<sup>2</sup> would thus be 28kL, disregarding effective rainfall.

The modelled results incorporated effective rainfall, thus providing a more accurate picture of garden irrigation needs. The highest theoretical garden irrigation use is in December (34.3 kL/month for property B), but the use remains quite high from October (25kL/month) to February (24kL/month). With reference to the indoor end-use results in Table 5, the monthly garden irrigation requirement for the relatively small plot (property A) is notably less than the monthly indoor end-use, irrespective of household size. In the peak month of December however, the garden irrigation use is almost the same as the indoor end-use for a one person household.

At this stage of the project, it is apparent that WDM measures should target indoor end-uses such as the toilet, shower, bath and washing machine for relatively smaller properties, but for larger properties, the focus should be on reducing garden irrigation.

## 4. FURTHER RESEARCH

As earlier mentioned, this study is part of a larger study commissioned by JW. Below is a list of items intended for investigation as the project proceeds:

- a) During the month of July 2016, fifty-six (56) smart meters were installed at a secure middle-income residential complex (housing 54 townhouses, 1 pool and a security hut) and at nine (9) stand-alone properties. Since the most significant residential indoor end-uses are the toilet, shower, bath, and clothes washing machine, time series data are currently logged at 15 second

intervals. At a 15 second interval, these notable indoor end-uses, as well as leaks, would be identified. Very low flow rates (or small flow volumes) and end-use events of a duration shorter than about 30 seconds would be missed, and hence, would be lumped together as miscellaneous use. Outdoor end-uses, such as pool filling and garden irrigation, would also be lumped together as these uses are typically relatively large and cannot always be described by distinctive patterns. Results of the current study would thus not allow for segregation of different outdoor uses or minor indoor end-uses despite the availability of actual water meter data.

- b) Analyses will be carried out on water use recorded prior and subsequent to the implementation of water restrictions within the City of Johannesburg for households within the study site.
- c) Surveys, using structured questionnaires, are currently underway to understand the socio-demographics of the households, end-use fixtures in homes, and how these impact on end-use.
- d) Typically, there is decreased per capita consumption with increased household size [12]. Further refinement of REUM will be undertaken to cater for this.
- e) The study will assess the impact of adjusting the frequency of use per end-use (specifically bath-shower, kitchen sink, dishwasher, washing machine and toilet) for different household sizes.
- f) Quantifying the impact of household or communal pools on water use within households would be valuable as pool water use is highly variable and a function of consumer behaviour.
- g) Washing machine event frequency and volume per event varies notably and will be quantified.

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## References

- [1] S. G. Buchberger and L. Wu, “Model for instantaneous residential water demands”, *J. Hydraulic Eng.* 121(3), pp.232-246, 1995
- [2] C.W. Howe and F. P. Linaweaver, “The impact of price on residential water demand and its relation to system design and price structure”, *Water Res. Research.* 3(1), pp.13-32, 1967.
- [3] H. M. Scheepers and H. E. Jacobs, “Simulating residential indoor water demand by means of a probability based end-use model”, *J. Water Supply: Res. and Tech – AQUA.* 63(6), pp.476-488, 2014.
- [4] H. E. Jacobs, B.E. Botha and A.A. Ilemobade, “Johannesburg Water End-Use Study: Deliverable 1 report”, compiled by Stellenbosch University and WITS University for Johannesburg Water, pp.1-31, June 2017
- [5] C. Fox, B. S. McIntosh and P. Jeffrey. “Classifying households for water demand forecasting using physical property characteristics”, *Land Use Policy.* 26(3), pp.558-568, July 2009
- [6] H. E. Jacobs and J. Haarhoff, “Application of a residential end-use model for estimating cold and hot water demand, wastewater flow and salinity”, *Water SA.* 30(3), pp.305-316, July 2004
- [7] F. P. Linaweaver, J. C. Geyer and J. B. Wolff, “Final report on Phase 1 of the residential water use research project”. Department of Environmental Engineering Science, Johns Hopkins University, October 1963.
- [8] DWS, Department of Water and Sanitation, (2016), Integrated Vaal River System - Limiting the use of water in terms of Item 6 of Schedule 3 of The National Water Act of 1998 for Urban and Irrigation purposes in the catchment areas of the dams supplying The Integrated Vaal River System and from The System [Online], Available:

- <https://www.johannesburgwater.co.za/wp-content/uploads/2016/08/Gazetted-Level-3-Water-Restrictions-12-August-2016.pdf> , date accessed 01 March 2017
- [9] Johannesburg Water, (2016), Water Restrictions for Johannesburg [Online], Available: <https://www.johannesburgwater.co.za/level-2-water-restrictions/> , date accessed 01 March 2017
- [10] K. Edwards and L. Martin, “A methodology for surveying domestic water consumption”, *Water and Environmental Management*. vol. 9, pp.477-488, 1995
- [11] C. Beal, R.A. Stewart, T. T. Huang and E. Rey, “SEQ Residential End Use study”, *J. Australian Water Association*. 38 (1), pp.80-84, 2011
- [12] H.E. Jacobs, “The first reported correlation between end-use estimates of residential water demand and measured use in South Africa”, *Water SA*. 33(4), pp.549-558, 2007
- [13] S. Massuel, J. Perrin, M. Wajid, C. Mascré, and B. Dewandel, “A simple low-cost method to monitor duration of groundwater pumping”, *Groundwater*, 41(1), pp. 141-145, 2009
- [14] B.E. Botha (2017) “Estimating household groundwater abstraction by means of a probability model”, Master’s thesis, Stellenbosch University, 2017 [Online], Available: <http://scholar.sun.ac.za/handle/10019.1/100900>
- [15] B.E. Botha and H.E. Jacobs, “An end-use model incorporating household groundwater as supplementary water source for garden irrigation”, Under review, *Water SA*.
- [16] C. Makwiza and H. E. Jacobs, “Sound recording to characterize outdoor tap water use events”, *J. Water Supply: Research and Technology AQUA*. accepted.
- [17] E.J.M. Blokker, J.H.G. Vreeburg, and J. C. van Dijk, “Simulating Residential Water Demand with a Stochastic End-Use Model”, *J. Water Resour. Plann. Manage.*, 136:pp. 19-26, 2010
- [18] K. A. Nguyen, H. Zhang, R. A. Stewart “Development of an intelligent model to categorise residential water end use events”, *J. Hydro-environment Research*. vol. 7, pp.182-201, 2013
- [19] K.A. Nguyen, R.A. Stewart, H. Zhang, “An intelligent pattern recognition model to automate the categorisation of residential water end-use events” *Environmental Modelling & Software* 47 pp. 108-127, 2013