

# ***ANALYSIS OF SHOWER WATER USE AND TEMPERATURE AT A SOUTH AFRICAN UNIVERSITY CAMPUS***

**BE Botha<sup>1</sup>, HE Jacobs<sup>2</sup>, B Biggs<sup>3</sup> and AA Ilemobade<sup>4</sup>**

<sup>1,2</sup>Department of Civil Engineering, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa

<sup>3</sup>JG Afrika, 14 Central Square, Pinelands, 7430, Cape Town, South Africa

<sup>4</sup>School of Civil and Environmental Engineering, University of the Witwatersrand, Private Bag 3, WITS, 2050, South Africa

<sup>2</sup>hejacobs@sun.ac.za

## **ABSTRACT**

*Earlier research has underlined that household end-uses form building blocks of the residential water demand pattern. Numerous end-use studies have been presented in the past, but none have reported on shower end-uses at Universities in South Africa. This research focuses on shower water use, as part of the first detailed end-use field study conducted in South Africa. An extensive desktop study was conducted regarding South African end-uses, focusing on shower use. Shower flow rate was physically measured under different conditions, while actual shower duration for the same showers was derived from water temperatures recorded over two periods of 5 days each, at 1 min frequency. The changes in temperature were used to estimate actual shower duration and event start times. The total shower event volume was stochastically determined by using Monte Carlo analysis. The average shower duration of the 759 shower events identified as part of this study was 9 min and 33 sec, with a flow rate of 8.7 L/min. The average shower event volume was 83 L/event.*

**Keywords:** Water end-use, shower, temperature

## **1 INTRODUCTION**

### **1.1 Shower as End-use of Water**

End-uses of water are considered to be building blocks of the residential water demand pattern [1]. The most notable indoor end-uses have been reported to be the toilet, shower, bath, and clothes washing machine [2]. End-uses of water can be extracted from time series data recorded at high spatial and temporal resolution by a consumer meter, employing software tools such as Flow Trace Analysis [3] or intelligent pattern recognition models [4]. Two models available for theoretical end-use analysis include SIMDEUM [5] and REUM [6].

According to earlier reports [5,6] the three parameters that influence water use for showers include event duration (D), frequency of use (F), the flow rate or intensity (I) - and of course the household size. Assuming a known household size, the focus shifts to D, F and I. Investigation into the type of geysers used to heat the water was not deemed necessary to meet the objectives of this study. The frequency of use was also not evaluated during this phase of the project due to various constraints.

### **1.2 Research Focus and Method**

The research team set out to assess shower event volume in communal bathrooms at two University residences. The focus was on the shower duration, intensity, and the derived shower event volume. Event volume was modelled stochastically, because it was considered impractical to measure the actual event volumes due to various constraints. The two key unknown model parameter values were the shower duration  $D$  and intensity  $I$ .

Shower duration notably impacts shower water use and it was considered necessary to assess actual shower durations. Shower duration was assessed for 15 different shower heads at two Stellenbosch University residences. Temperature loggers were used to record shower water temperature over two periods of three days each, at 1 min intervals. The variation in temperature of shower heads was used to derive shower duration and timing of each event. The temperature recorders provided estimates for duration instead of actual duration, but had numerous advantages when compared to other methods of measurement.

The intensity (flow rate in L/s) is a function of shower head design and the water pressure, which in turn is often influenced by the type of water heater (geyser). An additional uncertainty is introduced by the fact that consumers could throttle the flow rate by adjusting the shower taps, or outlet valve(s) at any time during the shower event. Three types of shower heads and sizes were tested in this study with fully open valves. Some shower heads control the flow rate (typically modulated to 9 L/s), for example with a pressure compensating flow restrictor, so it was not considered necessary to measure actual water pressure to obtain suitable results.

### 1.3 Objectives

The study was structured around the following objectives: (i) conduct an extensive desktop study regarding South African end-uses, focusing on shower use; (ii) record shower water temperature at various showers in two residences over two periods of 5 days each, at 1 min frequency, in order to estimate the actual shower duration and event start times; (iii) record selected shower flow rates and (iv) set up a stochastic model for shower event volume, using Monte Carlo analysis.

## 2 REPORTED SHOWER WATER USE

Published values for the per capita shower event volume vary notably, from about 30 L/p/d to over 100 L/p/d. The variation is also dependent on whether an individual prefers to bath or shower. The bath and shower share the same purpose - for personal hygiene - and are often reported on integrally in terms of end-use volume. The term “shower/bath” is used in literature and was adopted in this text as well. Earlier research [7] noted that the average shower/bath use volume from a number of other studies was 46 L/c/d, and reported 45L/c/d for the shower event volume in South East Queensland, Australia. The mean shower event volume in a North American study [8] was 59 L/event. The shower end use category has been identified as the largest portion of indoor consumption in another Australian study [9], with an average of 42.7 L/p/d, representing 33% of the total indoor consumption. Various other international end-use studies have also identified the bath/shower as the most notable indoor end-use. A summary of formerly published values noted

that the shower/bath contributed between 26% and 46% to the total indoor water use [2]. The shower has been noted to contribute about 15% to the total peak hourly indoor flow [10]. One study reported on shower water use in South Africa, suggesting an event volume of 92 L/p/d [11]. Some Municipal by-laws in South Africa stipulate 10 L/min as the maximum shower head flow rate, with the most common shower head based on sales volume of a leading supplier providing 9L/min according to specification - the latter has a pressure compensating flow restrictor. A shower event volume of 81 L/p/d was assumed [12] in a recent end-use analysis for homes in Johannesburg, based on 9L/min intensity and 9min shower duration.

The highest reported shower event volume in a study group of 28 homes in the UK [13] was 156 L/p/d, and another UK-study reported 150 L/p/d [14]. A reasonable upper limit for shower event volume is ~400 L/event, considering a relatively high shower nozzle flow rate (20 L/min) combined with a 20 minute shower duration (this study noted numerous shower event durations between 20-30min, so even with low flow nozzles the total event volume may exceed 300 L/event).

### **3 DESCRIPTION OF FIELD TESTS**

#### **3.1 Study Site**

Two residences were investigated at Stellenbosch University - one male and one female residence. The women's residence was labelled Residence A and the men's residence was labelled Residence B. Residence A is a 4-story building and Residence B is a 9-story building. The two study sites were chosen based on information provided by the facilities manager. The two residences represent typical women's and men's residences for the Stellenbosch University campus. Residence A has roughly 16 residents per shower and Residence B has roughly 6 residents per shower. The total duration of the shower investigation study was 3 weeks, from 27 February 2017 to 20 March 2017.

#### **3.2 Volumetric Measurement**

Flow rate measurements were taken using a measuring cylinder. For university residences, it is not uncommon for students to remove the shower head to increase water flow, but showers without showerheads were repaired and not included in the measurement sample. Selected showers were inspected and flow rates measured volumetrically. In this study, 3 measurements were taken on 5 floors (floor 2, 3, 5, 7 and 9) at Residence B, using 3 different shower heads (existing large flat, oxygenics, and shower power) in each case. The flow rates at the Residence A (floor 2 and 3) were assumed to correspond to measurements at Residence B, as confirmed with two volumetric tests at Residence A. The static pressure was not taken into account when simulating the flow rates, since the flow rate was measured and stochastic analysis accounted for uncertainties in variables.

#### **3.3 Temperature Measurement**

Shower head temperature was recorded by means of temperature loggers. The temperature variation was used to derive shower durations. The method of using temperature logging to identify event durations has been used successfully in the past [15, 16, 17] for groundwater flow from boreholes. Events are identified based on the difference between the recorded end-use outlet temperature (on the shower head in this case) and some baseline temperature, generally recorded simultaneously as control. However, having multiple showers in the same room meant that a separate baseline temperature was not needed and the events were determined by analysing the difference between the measured temperature and the room temperature. When there was an increase in temperature

(positive temperature gradient over a certain time step) an event was flagged, and the duration was determined using MS Excel and the time-series graph from Coldchain Thermodynamics. The end of each event was identified by the first subsequent negative temperature gradient. A relatively long event would thus show a temperature increase, followed by a sustained temperature during the shower event, and a temperature decline after the end of the shower event. Relatively shorter events would not have a sustained component (due to the logging frequency of 1 min). A sequence of events from the time series data at one of the shower heads is shown in Figure 1.

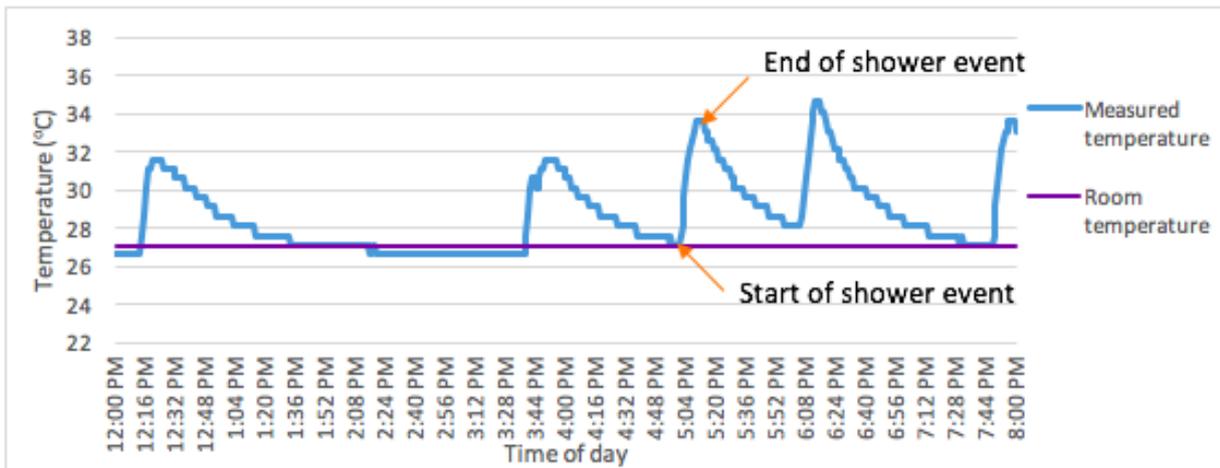


Figure 1. Identifying shower events

## 4 STOCHASTIC ANALYSIS

Monte Carlo analysis was used in this study to transform uncertainties in input variables to stochastic model outputs. Numerous software applications employ Monte Carlo method for risk analysis. @Risk, a commercial spreadsheet-based software programme by Palisade Corporation is available in South Africa and was used in this study. Input data are specified in Microsoft Excel and computed by adding different probabilistic distribution functions to the specified input cells. The software imitates the uncertain input variables using Monte Carlo simulations. The best distribution fit for the input variables and generated outputs are determined in @Risk by means of a goodness of fit (GOF) test, such as the Anderson-Darling test, chi-squared test and the Kolmogorov-Smirnov test. A basic shower end-use model was set up in Excel, using the @Risk add-in, to run a Monte Carlo analysis. The model stochastically describes the shower event volume as an appropriately selected value for duration multiplied by intensity.

## 5 RESULTS

### 5.1 Shower Flow Rate

Table 1 summarizes the flow measurements taken at the respective shower heads and the static pressure at each floor. The values were used as input variables for the shower intensity. The large flat shower heads are the existing shower heads at the residences. Although only the existing shower heads are analysed in this study, the other two shower heads were tested to evaluate potential future installations. The measured flow rates for all shower heads were less than locally reported typical values for showers, of 9-10 L/min [12]. The cumulative distribution function (CDF)

of all the measured flow rates is plotted in Figure 2 and the best fit distribution for the simulated flow rates (uniform distribution) was superimposed on the graph. The statistical parameters of the flow rate variable are summarised in Table 2.

Table 1. Residence B flow rates and pressures

Floor	Static Pressure (kPa)	Flow rate (L/min)		
		Existing	Oxygenics	Shower power
2	250	8.8	8.3	8.9
3	230	9.0	7.8	8.2
5	180	8.1	6.6	6.9
7	100	8.8	5.6	4.9
9	0	8.3	4.3	3.7
<b>Average</b>	152	8.6	6.5	6.5

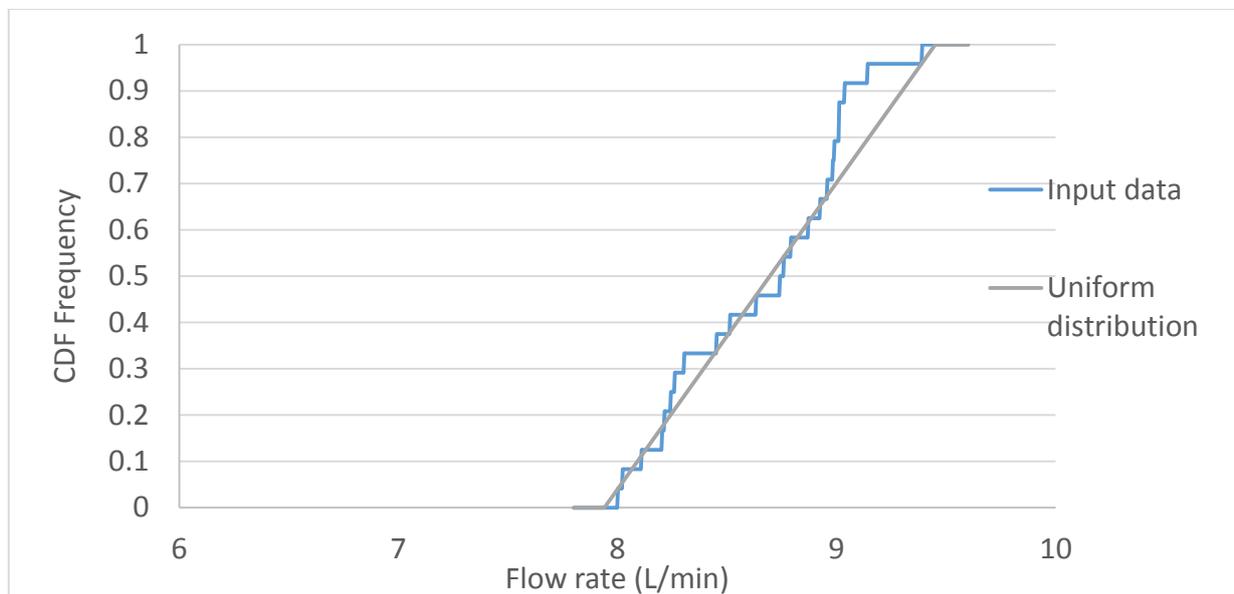


Figure 2. Cumulative distribution function (CDF): shower flow rate

Table 2. Statistical parameters for the shower flow rates

Variable	Distribution	Average	Minimum	Maximum
Intensity, I (L/min)	Uniform	8.69	7.940	9.450

## 5.2 Shower Duration

The temperature analysis, discussed earlier, successfully identified 759 shower events. The average duration was 9 min 33 sec with a standard deviation of 4 min 15 sec and maximum of 30 min. The peak shower frequency occurred during the morning (6AM – 9AM) and late afternoon (7PM – 10PM). The shower duration histogram is presented in Figure 3. The gamma distribution was selected as the best fit based on the overall ranking determined by the GOP tests. The CDF of all events is plotted in Figure 4 and corresponding statistical parameters are summarised in Table 3.

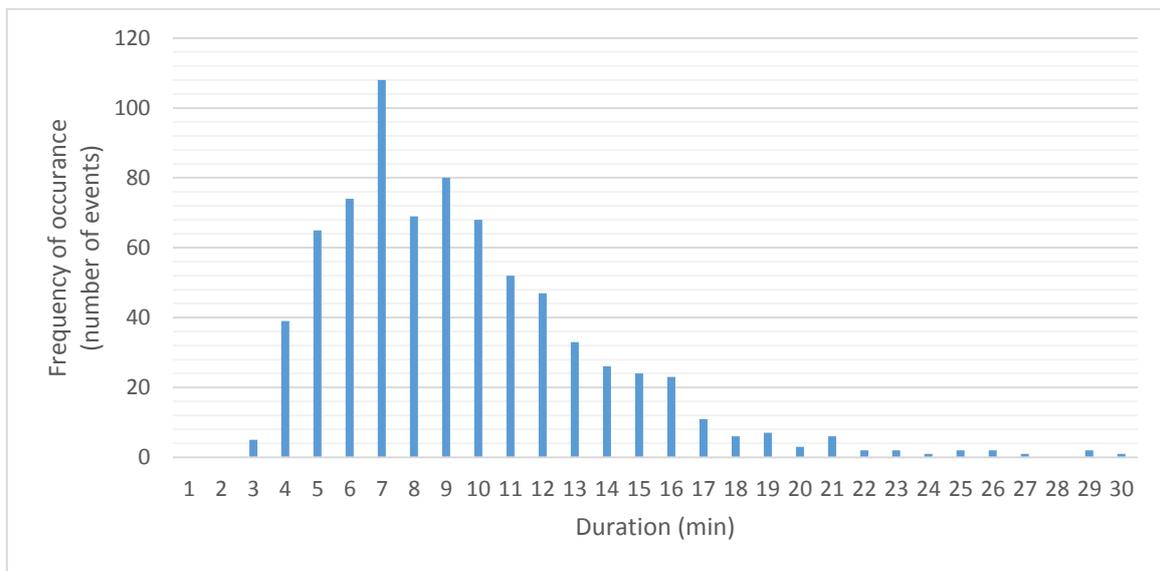


Figure 3. Shower event frequency

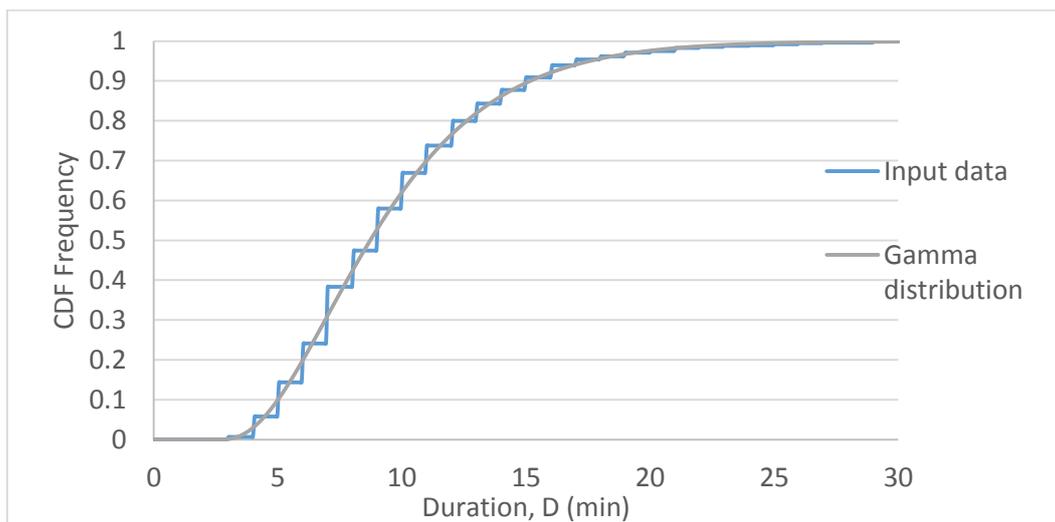


Figure 4. Cumulative distribution function (CDF): shower durations

Table 3. Statistical parameters for the shower durations

Variable	Distribution	Significance ( $\alpha$ )	Regression coefficients ( $\beta$ )	Shift factor
Duration, D (min)	Gamma	2.735	2.536	2.616

### 5.3 Shower Event Volume

The simulated input values were used to populate the shower end-use model. The CDF of the model results is plotted in Figure 5. Average shower event volume was found to be 83.0 L/event, with 90% of the events using more than 42L/event and 10% of the events using more than 135L/event. The results are similar to reported values from previous studies.

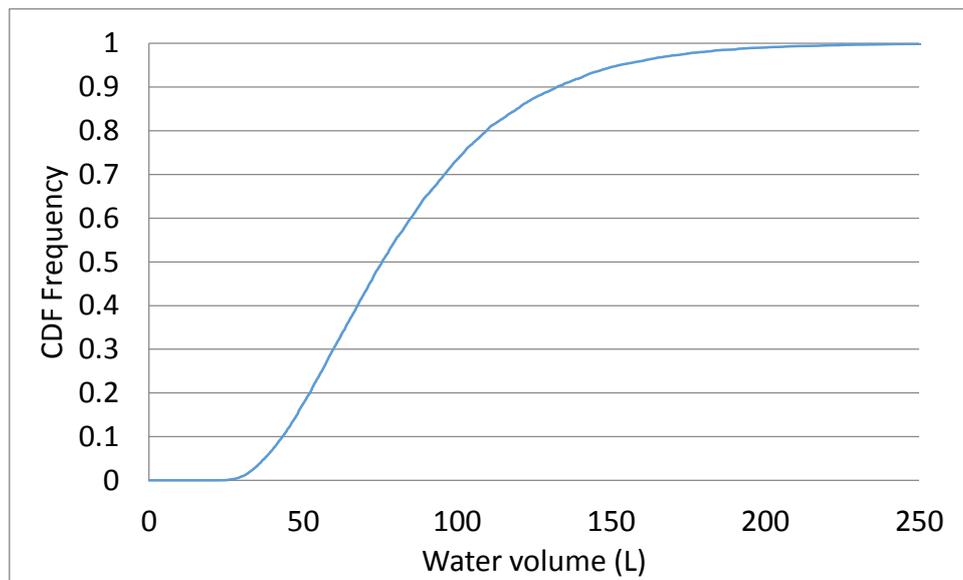


Figure 5. Cumulative distribution function (CDF): water consumption per shower event

## 6 CONCLUSION

The shower duration was derived from recorded temperature at shower heads in two University residences. Temperature loggers proved to be a simple, cost effective method to determine shower durations. The majority of shower events took place in the morning between 6 AM and 9 AM; and at night between 7 PM and 10 PM. The average shower duration was measured to be 9 min 33 sec with a standard deviation of 4 min 15 sec, in line with typical values reported in literature. The average intensity, or flow rate, was 8.7 L/min. The average shower event volume for the specific study site was determined to be 83 L/event.

### References

- [1] S.G. Buchberger and G.J. Wells, "Intensity, duration, and frequency of residential water demands", *J. Water Resour. Plann. Manage.*, Jan/Feb, pp. 11-19, 1996
- [2] H.M. Scheepers and H.E. Jacobs, "Simulating residential indoor water demand by means of a probability based end-use model", *J. of Water Supply: Research and Technology-Aqua* 63 (6), pp. 476-488, 2014
- [3] P.W. Mayer, W.B. DeOreo, E.M. Opitz, J.C. Kiefer, W.Y. Davis, B. Dziegielewsji, and J.O. Nelson, "Residential end uses of water", AWWA Research Foundation and American Water Works Association, 1999
- [4] 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
- [5] 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

- [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 J.*, 30(3), pp. 305-316, 2007
- [7] A.A. Makki, R.A. Stewart, K. Panuwatwanich and C. Beal, “Revealing the determinants of shower water end use consumption: enabling better targeted urban water conservation strategies”, *Journal of Cleaner Production*, Dec 1;60: pp.129-46, 2013
- [8] W.B. DeOreo, J.P. Heany and P.W. Mayer, “Flow trace analysis to assess water use”, *Journal American Wastewater Association*, January 1996: pp.79-90, 1996
- [9] C. Beal, R.A. Stewart, T.T. Huang and E. Rey, “SEQ residential end use study”. *Journal of the Australian Water Association*, 38 (1), pp. 80-84, 2011
- [10] A. Funk and W.B. DeOreo, “Embedded Energy in Water Studies Study 3: End-use Water Demand Profiles”, CALMAC Study Volume 1 of 1 Main Report, Prepared by Aquacraft, Inc. for the California Public Utilities Commission Energy Division, April 29, 2011
- [11] C.F. Schutte and W.A. Pretorius, “Water demand and population growth”, *Water SA J.* 23(2), pp. 127-133
- [12] 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, June 2017, pp.1-31
- [13] D. Butler, “A small-scale study of wastewater discharges from domestic appliances”, *Water and Environmental Management Journal*, 5, pp.178-185, 1991
- [14] C.S. Lauchlan and A. Dixon, “Modelling of water discharges for houses with conventional and low water use appliances”, *Advances in Water Supply and Management - Maksimovic, Butler and Mermon (Editors), Swets and Zeitlinger, Lisse*, pp.517-524, 2003
- [15] S. Massuel, J. Perrin, M. Wajid, C. Mascré, and B. Dewandel, “A simple low-cost method to monitor duration of groundwater pumping”, *Groundwater*, January/February 41(1), pp. 141-145, 2009
- [16] 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>
- [17] 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 J.*, submitted March 2017.