Research Paper

Diurnal water use patterns for low-cost houses with indigent water allocation: a South African case study

Dian Pretorius, Melissa Lauren Crouch and Heinz Erasmus Jacobs

ABSTRACT

The diurnal water use patterns are of interest to hydraulic modellers, as these patterns are required for the design of water distribution systems. An extensive body of literature is available with regard to daily, weekly and seasonal diurnal water use patterns of typical suburban houses. However, the characteristics of South African low-cost houses, the socio-economic status of the consumers and the level of water service to such houses differs from typical western suburban houses reported on elsewhere. Notable differences include the limited access to heated water and negligible garden irrigation at the low-cost houses. Knowledge of water use in low-cost houses, which are prevalent in South Africa, is limited. To reduce this lack of knowledge, approximately 2.5 million flow records were collected over a period of 3 years from a sample of 14 low-cost houses as part of this empirical case study. Subsequently, a diurnal water use pattern was constructed for the selected low-cost houses at 15-minute and 1-hour resolution. The diurnal pattern is useful for hydraulic modellers when data that represent extended period time simulation of water networks in low-cost housing developments is required.

Key words | diurnal patterns, low-cost housing, peak flow, water use

Dian Pretorius
Melissa Lauren Crouch
Heinz Erasmus Jacobs (corresponding author)
Department of Civil Engineering,
Stellenbosch University,
Private Bag X1, Matieland 7602,
South Africa
E-mail: *hejacobs@sun.ac.za*

INTRODUCTION

Government subsidised low-cost housing developments, with access to water services, are common in developing countries as a means to address the housing needs of the poor in an effort to meet the 2015 Millennium Development Goals (United Nations 2000) and later the Sustainable Development Goals (United Nations Development Programme 2016). Designers of the related water services for new developments rely on accurate water distribution system model results, which may be negatively affected by inappropriate guidelines for estimating water use. In the case of South African low-cost houses, the published water use guidelines pre-date the specific housing type under consideration, and thus may not be applicable to this unique housing type. Diurnal water use patterns are required by hydraulic modellers to conduct extended period time simulations of water distribution systems. However, water consumption data for low-cost houses are especially hard to obtain, even more so at a resolution of an hour or less.

VARIATION IN WATER DEMAND AND RELATED DEMAND PATTERNS

The average annual daily demand (AADD) is widely used for problems relating to research and design of water services in South Africa; a comprehensive description of the AADD is provided by Strijdom *et al.* (2017) and was adopted in this article without change. Many factors affect the diurnal variation of household water use. The time of the day when a consumer demands water drives the diurnal water

doi: 10.2166/washdev.2019.165

use pattern, which is attenuated by an increased number of consumers as water use events are super-imposed.

Monthly water use variation is often reported to illustrate seasonal fluctuation (Jacobs & Haarhoff 2007; Du Plessis *et al.* 2018; Makwiza *et al.* 2018). However, Ghavidelfar *et al.* (2018) reported on the summer and winter seasons exclusively, to explain seasonality. In a similar manner, the summer and winter seasons were segregated in this study as representing the high and low water use periods, respectively. Also, workdays have a distinct water use pattern and differ from non-working days. On non-working days (Saturdays and Sundays in South Africa), water use patterns are spread more evenly throughout the day, since people spend more time at home during the day. For this reason, weekdays and weekend days were also separately classified.

PEAKING FACTORS

Peak flow at any hydraulic model node could be obtained by multiplying the peak factor with the long-term average flow, typically the AADD. Peak factors are useful in developing countries where data availability may limit water network modelling to steady-state analyses. In steady-state models, the hourly peak node outputs are typically used as a representation of the system peak load case (Ghorbanian *et al.* 2016; Strijdom *et al.* 2017). Johnson (1999) noted that the 15-minute peak would approximate the actual instantaneous peak flow in a pipe network. Peak factors are discussed in more detail by Diao *et al.* (2010), Zhang *et al.* (2005), Barrufet (1985) and Tessendorff (1980). However, in an extended period simulation, the node outputs are modelled more accurately over a stipulated period of (say) 1 week with an array containing the hours and flow rates (node outputs) over the entire modelling period. Of course, the peak hour factor (as ratio of the daily average flow rate) would be the maximum of the 24 values in the hourly based diurnal water use pattern.

STUDY OBJECTIVE

A temporal measurement resolution of 15 minutes was required for this study to construct a diurnal pattern that would capture the peak flow rate and enable compilation of an hourly based diurnal pattern. The main objective of this study was to derive diurnal water use patterns for a sample of low-cost houses, based on measurements at a temporal resolution of 15 minutes. As part of this research, weekday and weekend diurnal water use patterns, as well as diurnal summer and winter water use patterns, were separately investigated.

LOW-COST HOUSING IN SOUTH AFRICA

A low-cost house (LCH), as it pertains to this study, needs to be placed in context. Figure 1 shows photographs of typical South African low-cost houses – the design, layout, house size and the plot size are relatively homogeneous. The floor area of an LCH is approximately 40–50 m^2, with relatively standard house designs of 8 m × 8 m and 8 m × 6 m being common. The total plot area varies between 128 m^2 and 240 m^2 (Shackleton *et al.* 2014; Fransolet 2015). Plots are almost always rectangular, with typical sizes of 20 m × 12 m, 16 m × 10 m or even as small as 16 m × 8 m being common. Gardens are generally absent or poorly maintained, although edible backyard garden crops are cultivated on a small scale at some houses, also using rainwater in cases where rainwater tanks were provided as part of the housing development (Dobrowksy *et al.* 2014; Fransolet 2015).

Low-cost houses typically have access to basic services such as potable water in-house, sewer (one toilet connected to a gravity sewer per house), electricity and roads (Goebel 2007; Govender *et al.* 2011). However, an LCH would have no access to piped hot water, unless installed subsequently by the homeowner. In some developments, such as the study area, hot water is made available via a solar geyser (Greyling 2009). Many consumers in low-cost houses would qualify as indigents based on the relatively low household income. An indigent water allocation of 6 kL per month per household, unique to South African disadvantaged communities, thus applies. This concept of ‘free basic water’ was initiated by the South African Government in 2001 (Smith 2010). The rising block tariff structure for indigents would include a block of 0–6 kL at no charge – the first 6 kL would be free regardless of whether more water was consumed.

Various terms have been used over the years to describe low-cost housing in South Africa. The term

Figure 1 | Typical low-cost houses in South Africa.

RDP-housing was coined in the period following the first democratic election in 1994 when low-cost houses were first constructed. The newly elected government's 'reconstruction and development programme', commonly called RDP, resulted in low-cost houses in the related housing developments being called 'RDP houses' (Cameron 1996).

Lodge (2003) estimated that between 1994 and 2001, about 1.1 million LCH units were built in South Africa, suggesting that households living in an LCH made up almost 15% of the total number of households in South Africa in 2001. According to the South African Government (Department of Human Settlements 2017), a total of 2,975,197 low-cost houses were completed between 1994 and 30 December 2017, implying a sustained construction rate of slightly more than 10,000 units per month. The relatively high and sustained rate of construction highlights the need for unique hydraulic model input parameters, in order to properly plan and design the relevant water infrastructure for low-cost housing developments.

MOTIVATION

Various studies presenting water use patterns, conducted internationally and within South Africa, are summarised in Table 1. None of the studies included houses that could be characterised as low-cost houses, as described in this study. Also, the South African studies are outdated and some publications even pre-date construction of the first LCH. The prevalence of low-cost houses in South Africa and commitment to a sustained construction rate of LCH developments, linked to the absence of available hydraulic model input parameters for water network modelling in LCH areas, points to a substantial gap in the available knowledge base.

Table 1 | Selection of studies reporting diurnal patterns for residential houses

Study location	Study direction	Reference
Australia	Impact of diurnal water use patterns on water supply network design	Lucas *et al.* (2010)
New Zealand	Monitoring summer and winter end-uses and studying improved efficiency of such	Heinrich (2007)
Australia	Combined water use pattern from water mains and rainwater harvesting in 20 households	Umapathi *et al.* (2013)
North America	Study of end-use patterns for 1,188 houses, across 12 study sites	Mayer & DeOreo (1999)
North America	Updated study based on the previous study by Mayer & DeOreo (1999)	DeOreo *et al.* (2016)
Australia	Comparing actual measured end-use results with survey-based estimates	Roberts (2005)
Australia	Quantifying the influence of residential water use – with different star-rated products – on average diurnal water use patterns	Carragher *et al.* (2012)
Nepal	Developing water consumption patterns from measurements of rooftop water tanks	Guragai *et al.* (2018)
South Africa	Investigation into seasonal variation and water demand patterns in South African cities	Garlipp (1979)
Gauteng, South Africa	Investigation into water usage in households within four different income brackets	Stephenson & Turner (1996)
Pretoria, South Africa	Investigation into water usage in high-, medium- and low-income households	Van Vuuren & Van Beek (1997)
South Africa	Influence of elasticity of water, pressure, income and stand area on water usage	Van Zyl *et al.* (2003)
South Africa	Estimation of the effect of stand area and stand value on water use patterns	Husselmann & Van Zyl (2006)

METHODOLOGY

A quantitative research study was undertaken to obtain water use data from low-cost houses in an LCH development. An empirical data analysis of the recorded water use was performed to produce diurnal water use patterns for low-cost housing, based on 20 sample houses. Water use was recorded at intervals of 15 minutes over a period of 40 months, allowing typical standard hourly diurnal patterns to be constructed.

COLLECTION AND PROCESSING OF DATA

Case study site

The LCH area of Kleinmond in the Western Cape Province, South Africa was identified as meeting the requirements for this study. A total of 20 houses were identified for installation of data recording equipment. The actual addresses of houses in the study sample were masked by hypothetical numbers. The plot sizes and the household sizes were determined by means of GIS-mapping, followed by site visits and a corresponding consumer survey. The average house floor area in the sample was 48 m^2, with an average household size of 3.9 people per household (PPH). The highest permanent occupation in the study group was seven PPH in a 48 m^2 house, which leaves 7 m^2 floor area per person on average.

Data loggers were installed at the 20 pre-identified houses and the flow rate was measured during the period of 28 September 2012 to 16 February 2016. The latest data reported in this article were downloaded on 16 February 2016. It was envisaged that more data would be recorded during 2017, but the battery voltage of most devices had dropped below acceptable levels and the record was terminated in February 2016. The data were transmitted to, and retrieved from, a GSM-based online remote monitoring system called MyCity (www.mycity.co.za). Each record contained a house number, water meter number, data logger number and the measured flow rate with the corresponding time and date of each measurement. The recording period interval for this study was

15 minutes, implying that ~2.4 million records were collected for analysis.

Data sorting and filtering

The data record for all houses included numerous zero values, reported by water meters registering no flow during a 15-minute period. Consecutive zero readings were common, as expected, and corresponded to times when no water would be used during that particular time. All days with zero readings for the whole 24-hour period were excluded from the analysis. In some cases, the system communication broke down temporarily and reported no flow rate. The data for all non-zero days were subsequently filtered to remove days with notable periods of missing data. It was considered appropriate to remove days with periods of more than 2.5 hours of missing readings (about 10% of a day).

Houses with fewer than 250 recorded days in total were also excluded from the study because the segregation of seasonal patterns would be compromised in cases where data did not span all seasons. Consequently, six houses (H10, H11, H15, H16, H17 and H18) were excluded. The following patterns were built for the remaining 14 houses:

- the average diurnal water use pattern, calculated over all 7 days of the week;
- the average diurnal weekday and weekend water use patterns; and
- the average winter and summer water use patterns.

DEVELOPING DIURNAL PATTERNS

The filtered database included fields for date, time and flow rate, with a table of 96 flow rate values, one per 15-minute period, for each house, per day. A diurnal pattern was subsequently derived for each house in the study sample. Each pattern was classified according to (i) weekdays versus weekend days and (ii) peak-summer versus midwinter. Ultimately, 56 unique diurnal patterns were derived for the 14 houses, with a summer weekday, summer weekend day, winter weekday and winter weekend day per house.

RESULTS AND DISCUSSION

Minimum night flow verification

Leakage at any house in the study sample would induce notable inaccuracy and required an investigation. The minimum night flow (MNF) was evaluated by inspecting the diurnal patterns. It was assumed that an MNF of $\leq$15% of the total daily water use was reasonable (McKenzie *et al.* 2012). All the houses in the sample, except house H06, satisfied the MNF condition. After an investigation into the flow patterns for house H06, a constant single leak event lasting 61 days was identified in the time series. The water use pattern for house H06 exhibited a relatively high MNF of 4.32 L per 15-minute interval (average flow rate of ~17 L/hour), which was equal to 77% of the total daily use during this period. The MNF value was deducted from all the 15-minute interval values of house H06 over the 61-day period and the resulting values were used for the subsequent analysis. All other houses had relatively insignificant MNF and the data were used without any changes.

Average diurnal patterns

The average diurnal water use patterns for all the analysed houses, together with the weighted average diurnal pattern, were plotted with MS Excel as presented in Figure 2. Two distinct water use peaks were observed. These peaks represent the typical morning and evening water use peaks, also reported for suburban houses in developed countries. The highest morning peaks for single, individual houses were about twice as high as the averaged value for all 14 houses combined. Analysis of the weekdays versus weekend days showed that weekday and weekend-day diurnal patterns were dissimilar. The weekday morning peak was lower than the weekend morning peak, whereas the weekday evening peak was higher than the weekend evening peak. Furthermore, the duration of the weekday morning peak was shorter than the weekend morning peak, as could be expected.

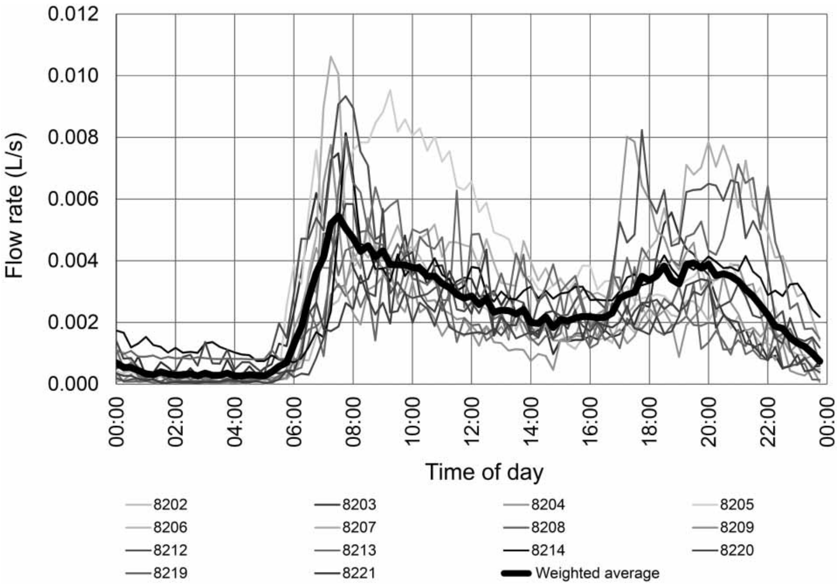

Figure 2 | Average pattern developed, together with all individual diurnal house patterns.

Average summer and winter diurnal patterns

The summer and winter average diurnal water use patterns were similar, as can be seen in Figure 3, suggesting no outdoor water use and insignificant influx of summer holiday visitors. Since LCH property sizes are relatively small, houses cover the largest part of the property, leaving limited space for gardening – also, privileges such as swimming pools and irrigated gardens that have been found to drive seasonal peaks, are exotic to the relatively poor communities addressed in this research. The absence of outdoor use coupled to the relatively constant nature of indoor water use (DeOreo *et al.* 2016) provides an explanation for the absence of a seasonal difference.

Dimensionless 24-hour pattern

An average dimensionless 24-hour pattern was derived for all LCH units and all days in the study sample. The 15-minute PF (peak flow) values for the average diurnal pattern

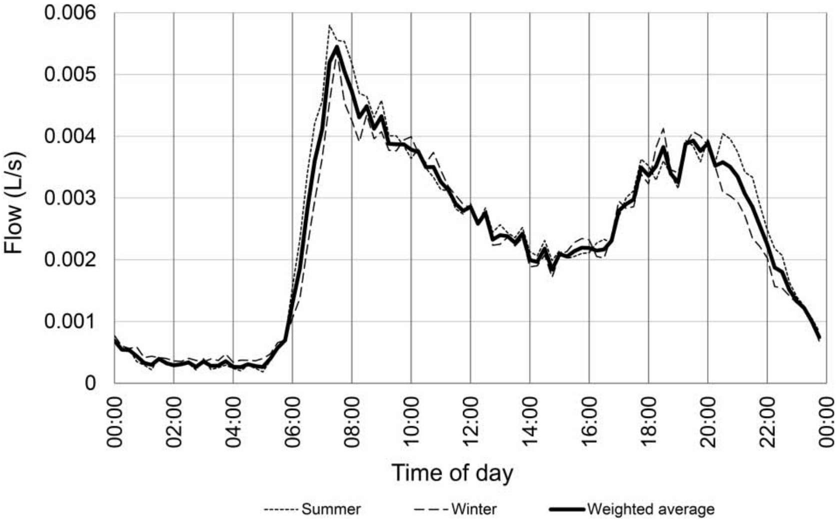

Figure 3 | Segregation of summer and winter diurnal water use patterns.

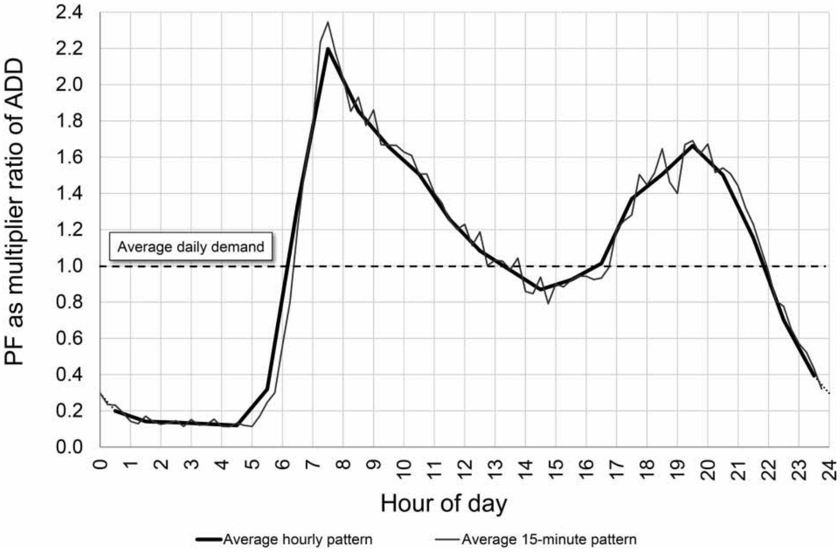

Figure 4 | Dimensionless 24-hour pattern for the low-cost houses.

and the hourly values were superimposed in Figure 4. The values are expressed as multiplier factors. The multiplier factors were obtained by dividing each of the hourly flows, from the weighted average pattern, by the average flow.

Discussion – diurnal pattern

The newly developed pattern appears to be very similar in shape to residential diurnal patterns reported elsewhere (Table 1) for typical suburban houses in developed urban areas, despite notable differences in the characteristics of the houses and in the socio-economic status of the consumers. The pattern derived during this research study shows a distinct peak occurring in both the morning and evening. The morning and evening peaks of the derived pattern have hourly peak factors of 2.197 and 1.663, respectively, meaning that water use during the peak hour is about double the daily average.

A follow-up survey confirmed that most of the consumers in the study area were employed and had children who attended formal schools, thus explaining the typical morning peak. At the time of the study, three of the houses had electrical water heating systems installed in addition to solar systems, whereas the others used the solar heaters (water was reportedly lukewarm or even cold on some mornings and on rainy days). Despite the limited access to hot water and other differences noted above, the diurnal pattern displays a clear and notable morning peak and evening peak.

Although sewer flow was not monitored as part of this study, the results could provide insight into sewer flow patterns as well. Sewer flows, in separate sewer systems, could be assumed to closely follow indoor water use patterns (Du Plessis *et al.* 2018). The diurnal water use pattern presented in this article could provide a reasonably accurate estimate of the diurnal sewage flow pattern.

CONCLUSION

Water use was recorded every 15 minutes for approximately 3 years in a relatively small study sample of 20 low-cost houses in the Western Cape, South Africa. The data were collated, filtered and subsequently investigated with respect to daily variation. In addition, weekday versus weekend day, as well as summer versus winter water use patterns were investigated. The resultant diurnal water use patterns for low-cost houses presented in this article are the first report of this nature in academic literature. The diurnal patterns found when plotting the 15-minute data and the 1-hour averaged data are practically similar, as were the winter and summer diurnal patterns. The diurnal patterns for weekday and weekend days were notably different. The dimensionless 24-hour diurnal pattern agrees with the general characteristics of water use patterns and peaks reported by others, with similar timing of the characteristic morning and evening peaks in suburban areas of developed countries.

The research could be elaborated on in future by extending the study sample. A need exists to study the effects of densification, where backyard shacks have been erected on low-cost housing plots. Backyard shacks are a common way for homeowners to generate additional income, especially for those who are unemployed, but in this study area, no backyard shacks were present. In view of further research, it could be hypothesised that the socio-economic status of occupants would notably impact the results, with the peaks being less pronounced and differently timed for regions with a relatively high unemployment level.

ACKNOWLEDGEMENTS

The Oppenheimer Memorial Trust (OMT) is greatly acknowledged for sabbatical financial support of Heinz Jacobs in 2018. The research would not have been possible without Overstrand Municipality collaborating on this interesting project. The authors greatly acknowledge the financial support of the South African Water Research Commission (WRC) as part of project K5/1995/3, which was conducted between 2011 and 2013. All flow readings recorded as part of this project were obtained via equipment funded by the WRC as part of project K5/1995/3. Mr Koos Vosloo (Flowtron; MyCity) is acknowledged for continued support to gather the data via the MyCity platform, even years after the conclusion of the project. Dr Jo Barnes, Community Health at Stellenbosch University, is credited for photographic contributions. Finally, it would be an oversight not to thank Prof. Jan Wium, Department of Civil Engineering at Stellenbosch University, for a valuable intimation.

REFERENCES

Barrufet, A. 1985 Survey of peak and average demand and their interrelating coefficients. *Water Supply Association* **6**, 316–319.

Cameron, R. 1996 The reconstruction and development programme. *Journal of Theoretical Politics* **8** (2), 283–294. doi:10.1177/0951692896008002009.

Carragher, B. J., Stewart, R. A. & Beal, C. D. 2012 Quantifying the influence of residential water appliance efficiency on average day diurnal patterns at an end use level: a precursor to optimised water service infrastructure planning. *Resources, Conservation and Recycling* **62**, 81–90. doi:10.1016/j.resconrec.2012.02.008.

DeOreo, W. B., Mayer, P. W., Dziegielwski, B. & Kiefer, J. C. 2016 *Residential Uses of Water, Version 2*. Water Research Foundation, Denver.

Department of Human Settlements 2017 *Delivery Serviced Sites and Houses/Units from HSDG*. Housing Delivery Statistics, Republic of South Africa. Available from: http://www.dhs.gov.za/sites/default/files/u16/HSDG%20to%20Dec%202017.pdf (accessed 26 October 2018).

Diao, K., Barjenbruch, U. & Bracklow, U. 2010 Study on the impacts on a water distribution system in Germany. *Water Science & Technology: Water Supply* **10** (2), 165–172.

Dobrowksy, P. H., Mannel, D., De Kwaadsteniet, M., Prozesky, H., Khan, W. & Cloete, T. E. 2014 Quality assessment and primary uses of harvested rainwater in Kleinmond, South Africa. *Water SA* **40** (3), 401–406. http://dx.doi.org/10.4314/wsa.v40i3.2.

Du Plessis, J. L., Faasen, B., Jacobs, H. E., Knox, A. J. & Loubser, C. L. 2018 Investigating wastewater flow from a gated community to disaggregate indoor and outdoor water use. *Journal of Water, Sanitation and Hygiene for Development* **8** (2), 238–245. doi:10.2166/washdev.2018.125.

Fransolet, C. G. C. 2015 *Universal Design for Low-Cost Housing in South Africa: An Exploratory Study of Emerging Socio-Technical Issues*. Cape Peninsula University of Technology. Available from: http://hdl.handle.net/20.500.11838/2271.

Garlipp, K. D. C. O. 1979 *Water Consumption Patterns in Urban Areas*. Published Master's Dissertation. University of Pretoria, Pretoria, South Africa.

Ghavidelfar, S., Shamseldin, A. Y. & Melville, B. W. 2018 Evaluating spatial and seasonal determinants of residential water demand across different housing types through data integration. *Water International*. https://doi.org/10.1080/02508060.2018.1490878.

Ghorbanian, V., Karney, B. & Guo, Y. 2016 Pressure standards in water distribution systems: reflection on current practice with consideration of some unresolved issues. *Journal of Water Resources Planning and Management* **142**, 04016023.

Goebel, A. 2007 Sustainable urban development? Low-cost housing challenges in South Africa. *Habitat International* **31** (3–4), 291–302. doi:10.1016/j.habitatint.2007.03.001.

Govender, T., Barnes, J. M. & Pieper, C. H. 2011 Housing conditions, sanitation status and associated health risks in selected subsidized low-cost housing settlements in Cape Town, South Africa. *Habitat International* **35** (2), 335–342. doi:10.1016/J.habitatint.2010.11.001.

Greyling, C. 2009 *The RDP Housing System in South Africa*. University of Pretoria. Available from: https://repository.up.ac.za/bitstream/handle/2263/14433/Greyling_RDP(2009).pdf.

Guragai, B., Hashimotot, T., Oguma, K. & Takizawa, S. 2018 Data logger-based measurement of household water consumption and micro-component analysis of an intermittent water supply system. *Journal of Cleaner Production* **197**, 159–1168. doi:10.1016/j.jclepro.2018.06.198.

Heinrich, M. 2007 *Water End Use and Efficiency Project (WEEP) – Final Report*. BRANZ Study Report 159. Judgeford, New Zealand.

Husselmann, M. L. & Van Zyl, J. E. 2006 Effect of stand size and income on residential water demand. *Journal of the South African Institution of Civil Engineering* **48** (3), 12–16.

Jacobs, H. E. & Haarhoff, J. 2007 Prioritisation of parameters influencing residential water use and wastewater flow. *Journal of Water Supply: Research and Technology – AQUA* **56** (8), 495–514.

Johnson, E. H. 1999 Short communication: degree of utilisation – the reciprocal of the peak factor. *Water SA* **25** (1), 111–115.

Lodge, T. 2003 The RDP: delivery and performance. In: *Politics in South Africa: From Mandela to Mbeki*. David Philip, Cape Town and Oxford.

Lucas, S. A., Coombes, P. J. & Sharma, A. K. 2010 The impact of diurnal water use patterns, demand management and rainwater tanks on water supply network design. *Water Science & Technology: Water Supply* **10** (1), 69–80. doi:10.2166/ws.2010.840.

Makwiza, C., Fuamba, M., Houssa, F. & Jacobs, H. E. 2018 Application of climate impact water use model to investigate change in domestic irrigation – a case study from Southern Africa. *Journal of Water, Sanitation and Hygiene for Development* **8** (2), 217–226.

Mayer, P. W. & DeOreo, W. B. 1999 *Residential End Uses of Water*. American Water Works Association, Denver.

McKenzie, R., Siqalaba, Z. N. & Wegelin, W. A. 2012 *The State of non-Revenue Water in South Africa*. WRC Report No. TT 522/12, Water Research Commission (WRC).

Roberts, P. 2005 *Yarra Valley Water 2004 Residential end use Measurement Study. Report by the Demand Forecasting Manager*. Yarra Valley Water, Mitcham, Australia.

Shackleton, C. M., Hebinck, P., Kaoma, H., Chishaleshale, M., Chinyimba, A., Shackleton, S. E., Gambiza, J. & Gumbo, D. 2014 Low-cost housing developments in South Africa miss the opportunities for household level urban greening. *Land Use Policy* **36**, 500–509. doi:10.1016/J.landusepol.2013.10.002.

Smith, J. A. 2010 How much water is enough? Domestic metered water consumption and free basic water volumes: the case of Eastwood, Pietermaritzburg. *Water SA* **36** (5), 595–606. https://www.ajol.info/index.php/wsa/article/view/61993/60542.

Stephenson, D. & Turner, K. 1996 Water demand patterns in Gauteng. *IMIESA* **21** (1), 11–16.

Strijdom, L., Speight, V. & Jacobs, H. E. 2017 Theoretical evaluation of sub-standard water network pressures. *Journal of Water, Sanitation and Hygiene for Development* **7** (4), 557–567. doi:10.2166/washdev.2017.227.

Tessendorff, H. 1980 Peak demands – results of the German research programme. In: *13th Congress of the International Water Supply Association*, 1–4 September 1980, Paris, France.

Umapathi, S., Chong, M. N. & Sharma, A. K. 2013 Evaluating of plumbed rainwater tanks in households for sustainable water resource management: a real-time monitoring study. *Journal of Cleaner Production* **42**, 204–214. doi:10.1016/j.jclepro.2012.11.006.

United Nations 2000 *General Assembly, Agenda Item 60 (B): United Nations Millennium Declaration*. http://www.un.org/millennium/declaration/ares552e.pdf.

United Nations Development Programme 2016 *Sustainable Development Goals*. Available from: http://www.za.undp.org/content/south_africa/en/home/sustainable-development-goals.html (accessed 18 February 2019).

Van Vuuren, S. J. & Van Beek, J. C. 1997 *Her-Evaluering van die Bestaande Riglyne vir Stedelike en Industriele Watervoorsiening gebaseer op Gemete Waterverbruike Fase 1: Pretoria Voorsieningsgebied (Re-Evaluation of the Existing Urban and Industrial Water Management Guidelines Based on Measured Water Abstraction Phase 1: Pretoria Provision)*, Report for the Water Research Commission by the Department of Civil Engineering, University of Pretoria, WRC Report No. 705/1/97.

Van Zyl, J. E., Haarhoff, J. & Husselman, M. L. 2003 Potential application of end-use demand modelling in South Africa. *Journal of the South African Institution of Civil Engineering* **45** (2), 9–19.

Zhang, X., Buchberger, S. G. & Van Zyl, J. E. 2005 A theoretical explanation for peaking factors. In: *Proceedings World Water and Environmental Resources Congress, Impacts of Global Climate Change*. https://doi.org/10.1061/40792(173)51.

First received 9 November 2018; accepted in revised form 20 March 2019. Available online 4 April 2019