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Investigation of household water consumption using smart metering system

Nicola Mead[a], Vasantha Aravinthan[b,*]

[a]*Toowoomba Regional Council, Toowoomba 4350, Queensland, Australia*
[b]*Australian Centre for Sustainable Catchments, University of Southern Queensland, Toowoomba 4350, Australia*
email: aravintv@usq.edu.au

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ABSTRACT

Prolonged drought currently experienced by South-East Queensland in Australia poses great challenges to water authorities to provide potable water for the communities in a sustainable manner. Toowoomba Regional Council (TRC) is implementing several demand management programs aiming to reduce the demand on potable water supplies, however little is known about their effectiveness. In this innovative project, a sample of 10 volunteer households was installed with high resolution smart meters and data loggers. The raw data were then collected remotely and processed with the special purpose software "Trace wizard" disaggregating every water event occurring in a household into relevant end-use categories. This paper gives insight into the itemized water consumption by each appliance during the monitoring period and further evaluates the effectiveness of implemented water demand management programs. The paper concludes that the provision of rebates for water efficient devices by both the State Government and TRC is currently targeted to the areas where they are likely to save the highest amount of water. However, WaterWise education is highlighted as a significant part of demand management programs with changes in consumers' behaviours likely to save the most water when compared to retrofitting of water efficient devices solely.

Keywords: Demand management; Smart meters; Water end use; WaterWise education; Water efficient devices

1. Introduction

Population growth accompanied by higher standard of living and ongoing drought conditions caused by changing climatic patterns tend to make water availability as a key international issue not only at present but for decades to come. The prolonged drought currently experienced by South-East Queensland in Australia poses great challenges to water authorities to provide potable water for the communities in a sustainable manner.

The city of Toowoomba located in South-East Queensland obtains water supply from three dams; Cooby, Cressbrook and Perseverance and a growing number of bores. Toowoomba Regional Council (TRC) provides water service to more than 90,000 people. Prior to the 1940's, the city's bulk water was sourced from the underlying basalt aquifer. As the city expanded, the bulk water source was supplemented with the construction of three dams; in the 1940's Cooby, 1960's Perseverance and 1980's Cressbrook Dam. Over time, more bores were installed to augment a dwindling surface water supply.

Water scarcity has also forced the utilities around the world to focus on efforts to conserve water. To ensure that water exigency does not exceed available supply, any urban water council needs to employ a variety of demand management strategies [1]. Toowoomba is no exception and demand management plays a crucial part in Toowoomba's strategy to address the continuing water shortage caused by the drought. Some of these demand management programs include imposing level 5 water restrictions to reduce the total water consumption banning outdoor water uses, mandatory installation of rainwater

*Corresponding author.

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tanks for new developments, and offering rebates to those who are willing to retrofit their fixtures with water efficient showerheads, dual flush toilets and front load washing machines that claim to consume less water. They also have "WaterWise education" programs that educate consumers about the importance of conserving water.

How effective are these demand management initiatives? Are the residents abiding by the imposed water restrictions? How does the attitude of the consumers affect the water consumption? For example, are the residents taking long showers when they use high-rated water showers or are they flushing twice when using dual flush toilets? Is the WaterWise education program working satisfactorily? Besides, the efficiency ratings of appliances are based on strict laboratory experiments under controlled environment, but are these fixtures performing the same way when installed in the field with different conditions, for example, pressures? The answers for these questions can only be verified by understanding the water end use.

In order to investigate the effectiveness of the implemented program and understand the end-use pattern, TRC undertook a pilot study to collect end-use data from 10 households in the city. In this paper, we aim to discuss the project outcome that gives insight into itemized water consumption by each appliance during the monitoring period and further evaluates the effectiveness of the already implemented water demand management programs. This paper answers the questions like where, when and how water is used in a typical household.

2. Methodology

High resolution smart meters capable of recording 72 pulses per litre were installed at each of the volunteer households. The collection of data was restricted to dwellings with their own water meter i.e. flats/units were not included in this study. Fig. 1 shows the meters used in this study.

The pulses from the meters were logged by Monita R Series Loggers, which captured data in ten-second intervals for a period of four months. The Monita loggers used were able to connect to the GPRS network and auto-report via email or SMS. This meant that it was not necessary to manually download data from each of the households. This was an advantage as householders were less exposed to the researchers and were more likely to "forget" that they were being monitored and hence their water use would be more representative. Fig. 2 shows the loggers that were used in this study.

These pulses logged during the study were then analysed using specific purpose software "Trace Wizard" developed by Aquacraft Inc. and disaggregated into separate end-use events. The events could be disaggregated according to a number of user defined parameters such as flow rate, volume and time. For example, a shower would be defined as having a peak flow rate between 7 L/min and 10 L/min and at least 2 minutes long but less than 20 minutes. Fig. 3 shows sample traces, note that washing machine event has a wash and two rinse cycles.

A sample of 10 volunteer households was selected for the installation of smart meters and data loggers for data collection. Number of samples was selected solely based on the availability of budget. Ideally speaking, the representative sample size required for a pilot study must be determined based on Equation 1, assuming a normal distribution of water consumption within a District Metered Area (DMA).

$$n = \frac{z^2\sigma^2}{E^2} \tag{1}$$

Fig. 1. CT5-S Meters (left) and installed (right).

Fig. 2. Monita R Series (left) and installed (right).

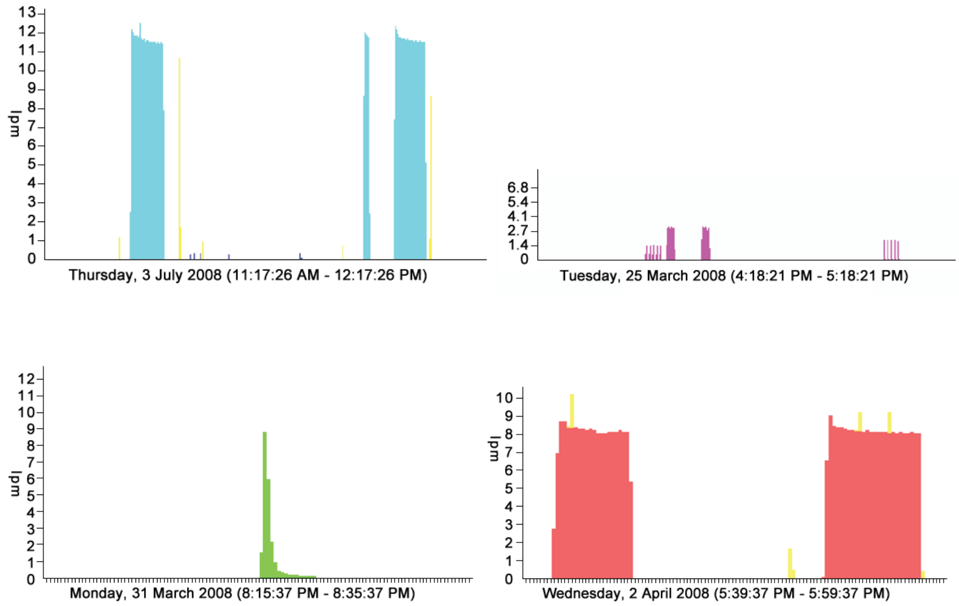

Fig. 3. Sample washing machine (top left), dishwasher (top right), toilet flush (bottom left) and showers (bottom right) traces.

where

n = Number of samples to be selected (to be determined)
z = Confidence level (assume 95% confidence interval, confidence level, z = 1.96)
E = Margin of error indicating our level of precision (say, for example, 10 L/household/day)
σ = standard deviation of water consumption of the population (to be found from previous billing data)

In order to determine σ, we can make use of the historic water consumption data from billing records for the whole population within a DMA. The variability of water consumption would be very high when there is high outdoor water consumption. However, in Toowoomba, at the time of this study, a level 5 water restriction was in place, which prohibited all outdoor water consumption. This means that all water consumption during the monitoring period is restricted to indoor use that has less variability. However, in this initial investigation, we focussed more on establishing a methodology for such end-use study. The results presented here were based on the observation of four months resulting in several events of washing, baths and toilet flushing in the observed households, which were then statistically evaluated.

3. Results and discussion

In this section, the implemented water demand management programs are discussed in detail and the effectiveness of them are quantitatively analysed.

3.1. How effective are water restrictions?

Toowoomba residents have been under Level 5 water restrictions since 26th September 2006. Under this level, all outside watering is prohibited, including the washing of vehicles and topping up of pools. The use of buckets directly filled from a tap is permitted for washing windscreens, mirrors and headlights of the vehicle and washing the wheelie bins and pets.

Almost no outdoor water use was detected during the monitoring period, although one household was suspected of watering their plants using a bucket. Other outdoor use was recorded but was related to the washing of pets and housings of pet animals which is permitted. Of the ten households under study, six had rainwater tanks. None of the rainwater tanks were connected to the indoor plumbing; hence this water was completely used for outdoor purposes. Water restrictions can be deemed to be working from this study because only a very small amount of water was detected for outdoor use. However, no data was collected on the social and economic impact that water restrictions had on the participants. Toowoomba's demand management program does consider ongoing permanent savings that can be achieved by the retrofitting of water saving appliances and fixtures.

Toowoomba Regional Council had set a target of 140 Litres/capita/day (Lpcd) for residents connected to the water supply system under level 5 water restrictions. Fig. 4 shows the average consumption values collected from the study and the estimate of water consumption as determined by Toowoomba Regional Council. This is done by summing the total volume of water from production data which includes both surface water and bores, using a factor that attributes water consumption to the various sectors of Toowoomba (residential, non-residential and unaccounted for water) and dividing this by the number of people who reside in Toowoomba. The consumption calculated by TRC is higher than what has been recorded in the ten households under study. But, both the household consumption and the TRC estimate fall well within that target of 140 Lpcd, which is promising.

It can be seen that Toowoomba residents were achieving this target for the majority of weeks during the study period with the exception of a few days. Water use during the start of the monitoring period were the lowest probably due to householders being aware that their water use was being monitored and hence used less water.

The consumption does not indicate any seasonal variations in water use due to water mainly used for indoor purposes. Water use can vary with seasons for a number of reasons, during hot summers people may take more showers, rainy weather could mean clothes washing is put off until a sunny day, but although these may be true, most seasonal variation is due to the outdoor water use. People water their gardens more during hot and dry days. For example, a similar study conducted in Perth which was not on water restrictions showed a much higher variability with high use of 658 Lpcd occurring during summer and a low use of 188 Lpcd during winter [2].

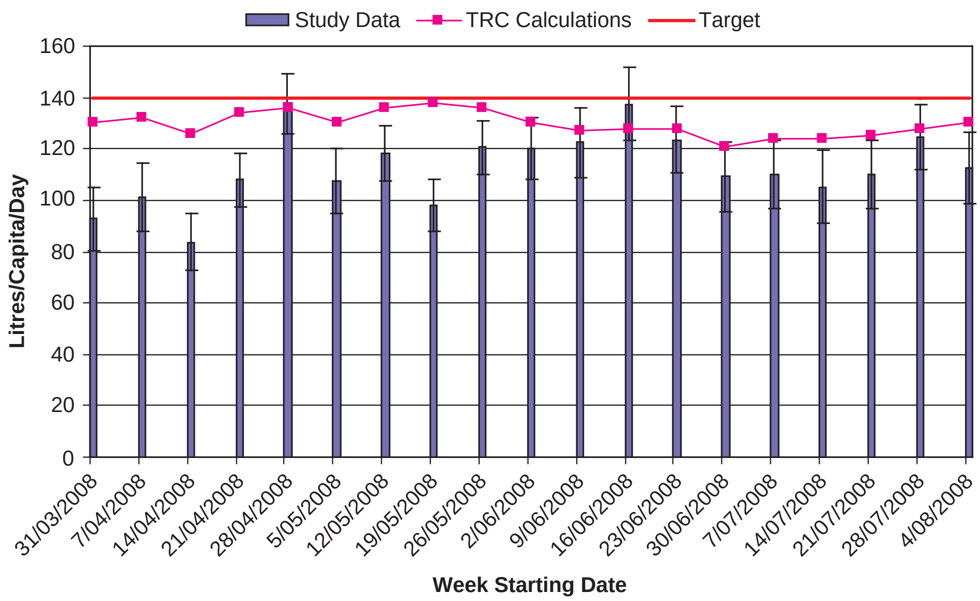

Fig. 4. Weekly average per capita use.

3.2. Rebates and retrofitting of water saving devices

Toowoomba Regional Council currently offers many rebates on water saving devices. These include:

- Rainwater tanks that are plumbed into at least one internal toilet and the laundry cold water tap
- The replacement of a single flush toilet with a dual flush toilet
- Recirculation device which circulates water in hot water lines back to the heater to be reheated
- Free Shower Rose exchange

The State Government currently offers a number of schemes that include:

- Home Waterwise service
- Rebates on rainwater tanks
- Clothes washing machines
- Dual flush toilets
- Swimming pool covers
- Greywater systems
- Garden Products

This study can give insight into whether some of the above schemes are really targeting those events that consume most water. The pie chart shown in Fig. 5 shows the proportion of indoor water used for each fixture or appliance. Shower use contributed the largest component of total water use at 43.5%. Washing machines used the second largest amount at 22.7%, followed by faucets at 15.5% and toilets at 12.76%. Leaks were minimal when compared to other studies at 0.36% (29.8% in EBMUD study [3], 2% [1]) ; most of these leaks were not constant. It appears that dripping faucets were turned off properly after a short period of time. The leakage in these households is small probably due to the newer age of the houses in this study or the awareness of the drought conditions which motivates people to locate and fix any leaks that they may have, using Home Waterwise Service. Not all households had dishwashers or used the bathtub so these values are relatively small. The outdoor use detailed here was found in only two households.

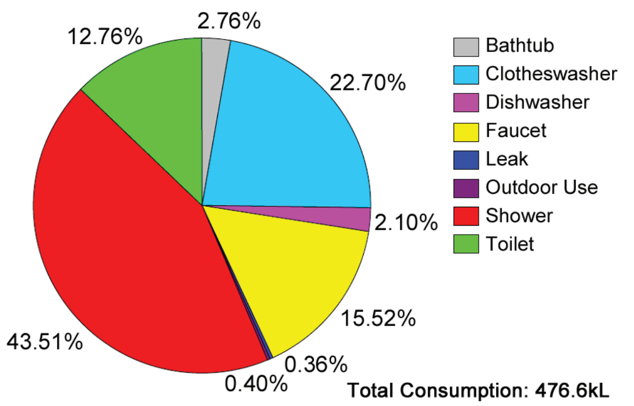

Fig. 5. Percentage volume consumed by fixtures and appliances.

TRC currently has a free shower rose exchange program, and has offered rebates on washing machines and the retrofitting of single flush toilets. These initiatives align well with the results from Fig. 5 as rebates and retrofitting of water saving devices are indeed targeting those water events that consume most water in a household. However, it is clear that TRC needs to place additional emphasis on shower use which is consistently high followed by washing machine and toilets, encouraging more and more people to retrofit their fixtures with water efficient ones.

3.2.1. Clothes washing machine

Washing machine is a volume based appliance, thus needing a fixed volume of water for its functioning. The volume of water consumed per cycle depends on the type of washing machine installed in the home. From this pilot study, there were two main types of washing machines identified; front load and top load. It was found that front load washing machines use an average of 60.6 ± 15.7 L/cycle, whereas top load washing machines use significantly more at 138.9 ± 23.9 L/cycle. The standard deviation is due to the different models, makes and sizes of the washing machines as well as the use of different cycles (i.e. cotton vs. speedy etc.). Manufacturers' estimates from current models put front load washing machines as using between 56 L and 70 L per cycle with top load as low as 62 L and up to 161 L per cycle.

The number of people living in a household affects the number of cycles/capita/week as economies of scale come into effect. For example, a single person may do 3 loads of washing per week (whites, colours and delicates) and these loads would generally be very small. A large household may do six loads of washing but these loads would always be full. Fig. 6 shows the effect household size (x) has on the number of cycles/capita/week (y) as indicated by the equation $y = 3.7\ x^{-0.71}$ with a strong correlation (R^2) of 83%. The trend line does not take into account the household with 3 occupants as this household was made up of university students who send some of their washing home. From this analysis, the lower the number of occupants, the higher the cycles/capita/week value which results in a higher volume of water needed. More investigation will need to be done to verify this trend.

Based on the investigation of the data collected, the parameters affecting the volume of water consumed by washing machines are volume/cycle, the number of cycles/capita/day and the capita/household. The following model is proposed to express the total volume consumed by washing machines.

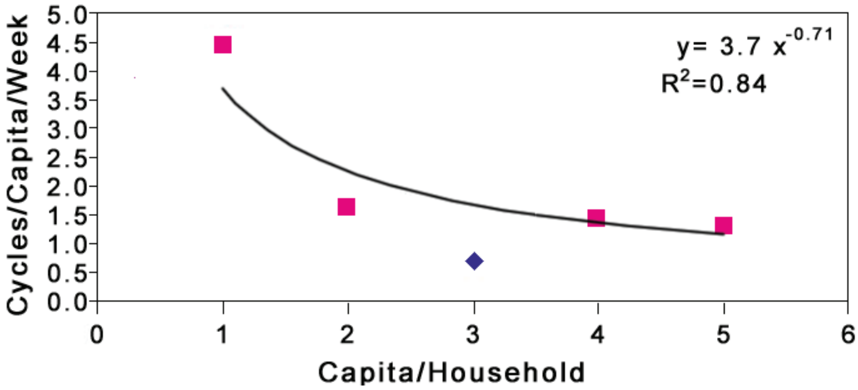

Fig. 6. Cycles/Capita/week variation with capita/household in washing machine use.

$$\text{Volume}_{\text{Total}} = \frac{\text{volume}}{\text{cycle}}\sum(\text{front load, top load}) \times \sum\left(\frac{\text{No. cycles}}{\text{capita}\times\text{day}} \times \frac{\text{person}}{\text{household}} \times \text{ No. households}\right) \times \text{No. days}$$

This model demonstrates that the water use of washing machines is dominated by the appliance itself and the occupancy of the home. Hence, to reduce the water use by washing machines, the uptake and retrofit of front load washing machines need to be encouraged. WaterWise education can only target the behaviour of the consumers by encouraging them to use larger less frequent loads to use with full capacity of the washing machine. This can have an effect on number of cycles/capita/day.

3.2.2. Showers

Toowoomba Regional Council has a free shower rose exchange where residents can bring in their old showerhead and get it replaced for free. More than 10000 residents have already taken up the offer, which advertises that up to 64 litres can be saved per shower. Shower timers are regularly given out to schools for free to encourage residents to cut their shower time down to four minutes. Showers and faucets are flow based appliances. The parameters affecting the volume of water used are the flow rate, the length of the event and the number of events/capita/day.

The shower flow rate is dependant on the type of shower used in the home. There are three types of showerheads in this study; Ultra Low Flow (ULF), Low Flow (LF) and Normal showerheads. Fig. 7 shows the average flow rates of the devices encountered in this study.

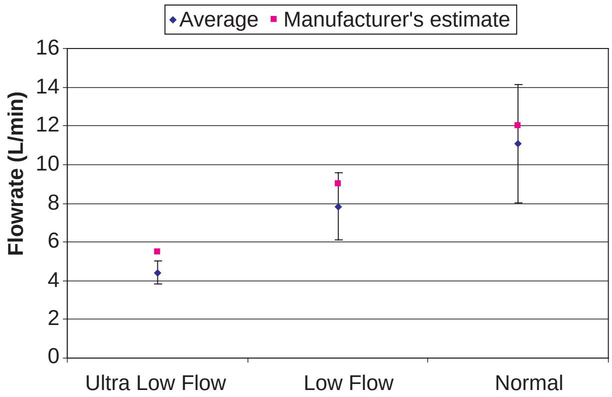

Fig. 7. Showerhead flow rates.

The average flow rate of each of these showerheads is lower than the manufacturer's estimates. This could be due to differences in the opening of the taps and differing pressure. The low flow showerheads show that while most showers fall below the estimated flow rate, it is still possible to exceed this, albeit in only a few cases. The ultra low flow showerhead performed very well in this study, showing a much lower flow rate and with participants unable to exceed the manufacturer's estimate.

The average duration of showers is shown in Fig. 8.

The average duration for all showers is 7.2 ± 4 minutes, with a median time of 6.3 minutes. Most showers fall between three and eight minutes, with a significant number exceeding the 15-minute duration. TRC encourages residents to have four minute showers to ensure that most water is saved; this is not reflected in the recorded data with 73% of showers recorded above this duration. Fig. 9 shows the average duration of showers by type of showerhead.

Ultra low flow, low flow and normal showerheads have an average duration of 13.9 ± 7.1, 6.8 ± 3.6 and 6.9 ± 3.1 minutes respectively. Although the ultra low flow showerhead has a much higher duration, only one

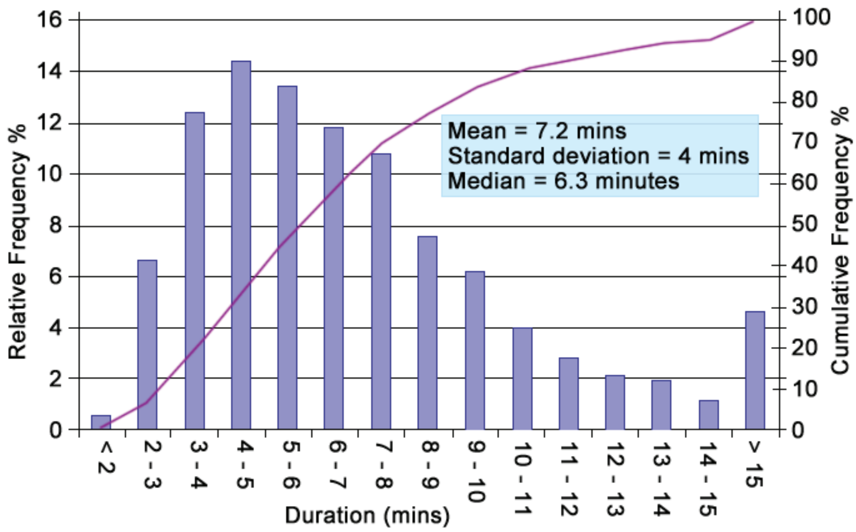

Fig. 8. Relative frequency of shower durations.

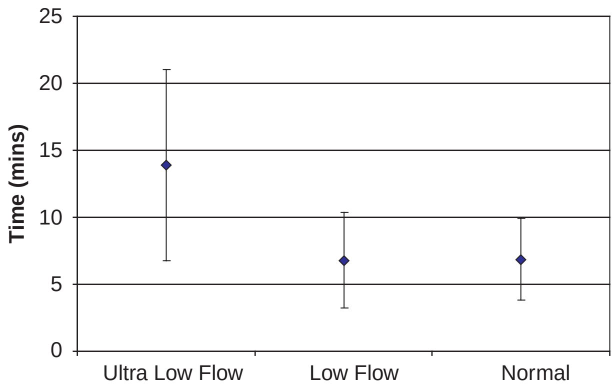

Fig. 9. Variation of shower time with showerhead flow rates.

person was using this type of showerhead so the duration is probably related more to the attitude of that person rather than to the type of showerhead.

The number of showers/capita/day is affected by the number of children in the household. There is a decrease in the number of showers taken per day as the number of children present in the household increases due to them either sharing showers, having navy showers (no turning off shower before next person gets in) or people taking baths. From this analysis the total volume used in showers can be calculated using the formula:

$$\text{Volume}_{\text{Total}} = \Sigma\left(\text{Shower Flow Rate} \times \frac{\text{Time}}{\text{Shower}}\right) \times \Sigma\left(\frac{\text{No. Showers}}{\text{captia} \times \text{day}} \times \frac{\text{captia (agegroup}}{\text{household}} \times \text{No. households}\right) \times \text{No. Days}$$

Reducing the flow rate of showerheads is useful in reducing water consumption by showers but reducing the time spent in the shower has the most effect on water consumption of showers. For example, installing a low flow showerhead will save approximately 28 L during a 7 minute shower, keeping the original showerhead and reducing duration to 4 minutes saves 33 L/shower. Using a low flow showerhead and a shorter duration shower will save up to 49 L/shower. It is important that WaterWise education focuses on the duration of showers as a key factor in saving water, it is important that consumers do not assume just because they have installed a water efficient showerhead, they can then take longer showers. Water savings from the installation of low flow showerheads were estimated at 27 L/shower at the average duration of 7.2 minutes. Ultra low flow showerheads could save significantly more water than this but consumers may experience dissatisfaction with the low level of flow and hence extend their showers negating any potential water savings.

3.2.3. Toilets

Fig. 10 shows the average volume of water consumed by different types of toilets. The manufacturer's estimates for single flush toilets vary with the size of the toilet. Both households, that had single flush toilets and dual flush toilets installed had 9 L cisterns although both of these toilets when investigated were set at a lower level than the full mark, hence the lower average value. The higher values can be related to holding the handle down or double flushing. There is no data available for the hold down toilets as to what average volume is used as it would vary dramatically between consumers.

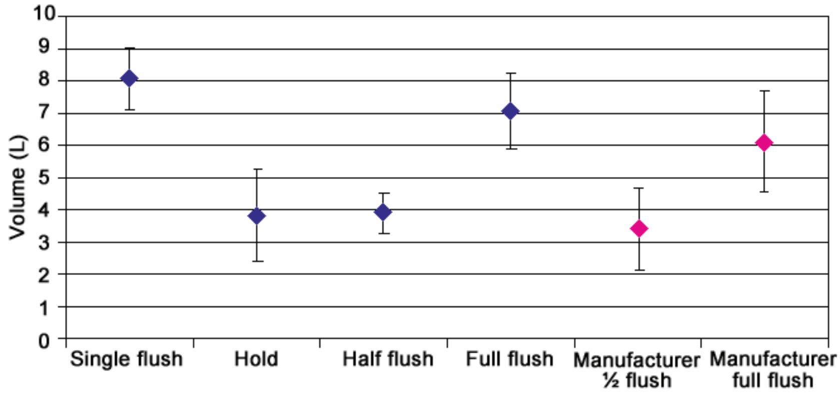

Fig. 10. Toilet flush volumes.

The variability can be clearly seen with the standard deviation of hold down toilets being 1.4 L. The results collected for dual flush toilets show that they have larger flush volumes than manufacturer's estimate. This could be due to consumers holding the button down or some of the faucet use from washing hands being included in the flush volume. The ratio of half to full flush was found to be 65.6–35.4% which correlates well with the EBMUD study [3] which found that the value is about 60:40.

3.3. *Effectiveness of waterwise education*

Education plays a large role in water demand management as it aims to change the attitudes and habits of people to save water. Some initiatives of TRC include programs such as "Let's Slow the Flow program", Shower Timers, WaterWise garden examples, education resource book for schools and television advertisements.

All these initiatives aim to influence the behaviour of participants in relation to their water use. The length of showers is significantly higher than the four minutes that is encouraged by TRC and the Queensland Water Commission. The majority of showers in fact are above 4 minutes in duration. The water that can be saved if all residents were using low flow showerheads and of 4 minutes in duration would be 967 ML/year, even if shower heads were not low flow, the water saved would still be significant at 832 ML/year. This represents a huge saving in water attributed to only an attitude and behavioural change.

Washing machine water efficiency is also based on economies of scale and consumers need to be encouraged to use their washing machine to its full capacity to ensure that the water savings are not negated by the increase in the number of loads done. If all consumers cut down their washing by just one load per household per week, a savings of 248 ML/year is possible while maintaining the same washing equipment. If this is done in conjunction with changing to water efficient washing machines, the total savings could be closer to 700 ML/year.

The water savings estimated by the replacement of single flush toilets with dual flush is very significant with substantial water savings possible if hold down toilets were retrofitted throughout the city. However, the household with the hold down toilet expressed dissatisfaction with the performance of this type of toilet so this may not be a viable option for consumers. The installation of a rainwater tank that is connected to at least one toilet and the laundry tap could save up to 48.4 Lpcd. If all households in Toowoomba had a rainwater tank that was used for indoor use a total saving of 4.7 ML/day could be saved.

The behaviour of participants in this study was impacted dramatically by the installation of the monitoring devices as was evident by lower water use during the first few weeks of the study. It is therefore suggested that TRC investigates implementing an ongoing monitoring program that encourages residents to be accountable for their water use and water use behaviour. This could take the form of self monitoring e.g. reading their water meter everyday to determine the household's daily use and comparing this to water use targets. From this study, it can be seen that WaterWise behaviour is crucial in managing water demand as it is a key input into calculating the total volume used by appliances and fixtures. While this study revealed interesting patterns regarding attitude and behavioural changes, the study should extend to a larger number of households with the involvement of diverse community members, which can reveal more interesting patterns and attitudes of wider community to water consumption and conservation.

4. Conclusion

This pilot study has proved that smart meters can provide detailed data about itemized water consumption in a household, which can be used to reveal the effectiveness of water conservation appliances and fixtures. Significant indoor water savings can be achieved through the installation of high efficiency plumbing fixtures and appliances. Detailed data analysis has provided insights into the variables that affect water consumption by appliances and fixtures. This study found that TRC is indeed targeting the demand management programs in those areas where most water is spent. However, WaterWise education is highlighted as a significant part of demand management programs with changes in consumer's behaviour likely to save most water when compared to retrofitting of water efficient devices solely.

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