Insights into Household Water Use Behaviours Throughout South East Queensland During Drought

Peter Coombes
Independent Scientist, Urban Water Cycle Solutions, Newcastle, Australia
E-mail: thecoombes@bigpond.com

This paper describes the water use behaviour of households throughout South East Queensland that was monitored using mini smart meters during the period February 2009 to May 2010. The monitoring program was combined with audits to define the characteristics of each household and each household also completed a water use diary. Households with higher incomes were more likely to include water efficient appliances and rainwater tanks which explained the small increases in per-capita and household water demands associated with households with higher incomes. Per-capita water use was found to be strongly dependent on the reported frequency of showering. Households without rainwater tanks had an average daily mains water demand of 514 litres and a per-capita daily demand of 139 litres. Households using rainwater for outdoor use had an average daily mains water demand of 383 litres and a per-capita daily demand of 117 litres – annual savings of 47.8 kL. Households using rainwater for indoor and outdoor uses had an average daily mains water use of 268 litres and a per-capita demand of 63 litres – annual savings of 89.8 kL. The performance of households using rainwater for indoor and outdoor uses exceeded the requirements of Queensland Development Code MP 4.2.

1. INTRODUCTION

This independent study was originally commissioned by the Queensland Water Commission (QWC) in response to a request from the Auditor General and carried out by the author and colleagues (formerly Bonacci Water). It is a snapshot of the longitudinal impacts of water efficient appliances and rainwater tanks on residential water use during and after the recent drought throughout South East Queensland (SEQ). Metering results were combined with responses to questionnaires and water use diaries to develop an understanding of water use behaviours throughout the SEQ region. Approximately 50 households in the SEQ region were randomly selected for the survey. Mini smart meters were installed at each property and participants were asked to complete questionnaires about their households. Each household also completed a water use diary over a period of 30 days that outlined key water uses on each day. This paper provides an overview of the results of the unique monitoring project that has directly observed water use at a range of households.

2. METHODS

Approximately 325 households were invited to participate in this study (via email, telephone and letter drops). It was expected that a higher number of people received this invitation as those contacted directly were encouraged to forward on the details and recruit colleagues, family and friends. A total of 76 households from all areas throughout SEQ responded as willing to participate in the study. However, 31 of the households were excluded from the investigation due to water meters on their properties that were not compatible with the smart meter technology and 3 households did not ultimately complete the monitoring program. Questionnaires and water use diaries were issued to participating households and water use was observed at 6 minute intervals at each household during the period February 2009 to May 2010. The main objectives of the end use study were:

1. Collect data on residential water usage;
2. Identify water use patterns and trends;
3. Reveal the use of water saving measures and behaviours; and
4. Understand the impacts of variations in climate on water use behaviours

Careful planning was required to ensure a selection of appropriate households that also accounted for the logistics of collecting and processing the data. Our study equally targeted four regions throughout the SEQ area, Brisbane, Gold Coast, Toowoomba and Sunshine Coast, to ensure a mix of residential properties across the regions. This process increased the logistical difficulty of installing smart meters and subsequent data collection. Nevertheless, the study aimed to include a wide variety of locations and demographics. Detailed planning of the water use study began in late 2008. A brief summary of this process is provided as follows.

Contact was made with the residents of residential properties in the 4 study areas (Brisbane, Gold Coast, Toowoomba and Sunshine Coast). Several different approaches were utilised to ensure participation of a random and varied group of residential properties. Participants were randomly selected from the White Pages telephone directory and were invited to participate via telephone, by mail drops in selected areas, by emails to business and community networks, and via word of mouth (participants in the study forwarding the study details to friends, family and colleagues). An initial invitation letter was sent to all participants explaining what the survey was about and what would be required of the participants.

Collect and compile contact details of residential properties willing to participate in the study. Create detailed questionnaires and water use diaries that were distributed to participating residential properties. This was a crucial part of the study that details indoor and outdoor appliances and water use behaviours critical to the overall analysis.

Questionnaires and water use diaries were sent to participants. Participants were also advised that the installation of the mini smart meters would commence in early February 2009. Self-addressed and stamped envelopes were also included to ensure a timely response by participants. A schedule to install meters at all participating properties was undertaken during early February 2009. The mini smart meters were installed during a three week period. When residents were onsite during the installation process, researchers explained the operation of mini smart meters and provided contact details for any queries or issues. When residents were not onsite during the installation process, researchers left introductory packages to explain the study and the operation of mini smart meters. Contact details were provided for any queries or to resolve issues.

At some locations mini smart meters could not be installed due to incompatible water meters. Letters were sent to households advising that their water meter was unsuitable and that their property could not be included in the study. Researchers visited residential properties during the period February 2009 to May 2010 to download data from the mini smart meters. During the period February 2009 to May 2010, all data were collected and analysed from mini smart meters and from the returned questionnaires and water use diaries. Statistical analysis of data from each site was used to determine the major variables affecting residential water use. During the period March to May 2009 residential properties were contacted via telephone and email reminding them to complete the questionnaires and water use diaries.

Mini smart meters and data loggers were fitted to water meters at all households to continuously record water use. Water use data was stored on the data logger and downloaded throughout the project. The downloaded data was then validated for timing, total water use and quality of data by manual observations of water use from household water meters.

3. RESULTS AND DISCUSSION

The responses to the questionnaires revealed a diversity of household water use characteristics and water related infrastructure. The only characteristics found to be common to all of the surveyed households was that none of the households were connected to a centralised recycled water system and an absence of single flush toilets. Only one household had a single flush toilet installed in addition to other dual flush toilets on the property. Two of the households in the study were found to have significant mains water leaks during the monitoring period. One of households was found to consume approximately 2,100 litres/day and the other approximately 1,700 litres/day of mains water. These leaks represent a significant volume of water in comparison to average household water use. Daily water use in these properties was more than 5 times larger than the average household water use of the study. The average per-capita water use for households in the study was 98 L/day and the average household size was 3.75 persons. The relationship between average daily water use in households and the size of households is presented in Figure 1.

Figure 1 reveals a non-linear relationship between average daily household water use and household size. These results indicate that per-capita water-use diminishes with increases in household size which is consistent with current research (such as Cui et al., 2008). The distribution of household sizes in this study is shown in Figure 2 and compared to the distributions of household sizes in the major areas of the region sourced from the Australian Bureau of Statistics (ABS, 2007) shown in Figure 3.

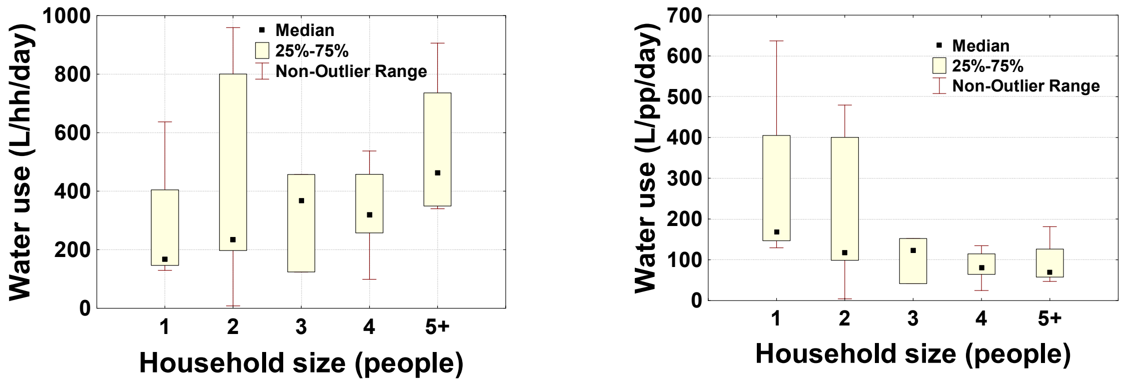

Figure 1: Household water-use versus household size.

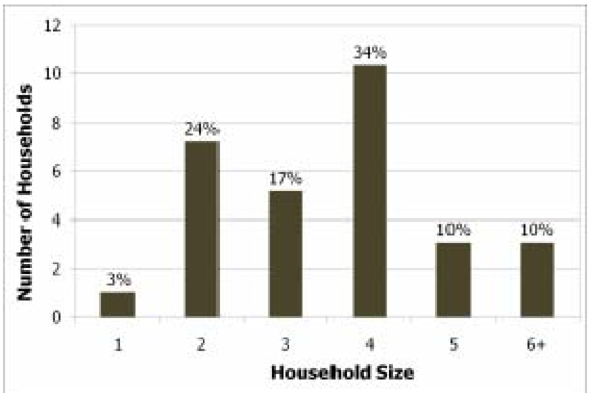

Figure 2: Distribution of households in the study

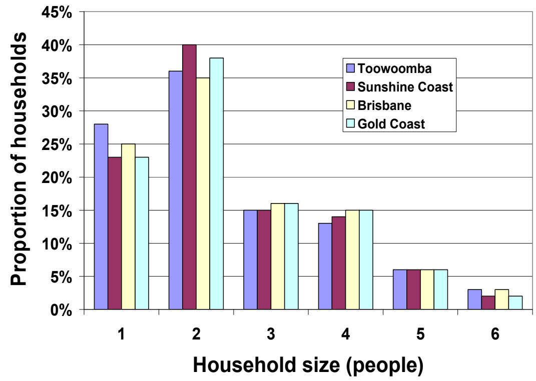

Figure 3: Distribution of households in SEQ

Figure 2 shows that the distribution of household sizes in the study was dominated by households with 2, 3 and 4 residents. Comparison with the distributions of household sizes in SEQ shown in Figure 3 reveals that the cohort of households in the study has significantly fewer one person households and a greater proportion of 4, 5 and 6 person households. This difference is explained by the study's focus on detached housing due to metering constraints that has resulted in a limited presence of units and apartments in the cohort that are expected to be mostly 1 and 2 person households whilst detached housing will consist of a greater distribution of household sizes. The return of questionnaires and water use diaries allowed detailed verification of the continuous water use data from the mini smart meters to determine the characteristics of the end uses of water in households (water use for showers, toilet flushes, washing machines and so on). Data from the mini smart meters was calibrated to individual flow events at various household fixtures as described by flow rates, timing and magnitude of water use events. The description of appliances and water use behaviour from questionnaires was vital to this process. A summary of household characteristics is shown in Table 1.

Table 1: Summary of household characteristics

Income ($1000 /hh/yr)	Houses	Household size (people)	Per-capita use (L/day)	Household water use (L/day)			Rainwater tanks	Water efficient fixtures
				Ave	Min	Max		
0 - 30	3	3	109	328	173	637	2	2
30 - 60	5	2	94	187	8	959	3	2
60 - 90	5	5.6	86	481	293	565	4	2
90 - 120	6	3.4	116	394	225	801	2	3
120 +	13	4.9	113	441	99	906	10	10

Table 1 shows that larger household sizes and daily water use were associated with higher incomes which resulted in a trend to larger per-capita water use for households with higher incomes. The use of rainwater tanks was fairly uniform across all income groups and a greater adoption of water efficient appliances was apparent for higher income households. The greater proportion of rainwater tanks and water efficient appliances in households has assisted with reducing household and per-capita water use in those households. Clearly a higher income may be related to a greater capacity to invest in water saving measures. It is noted that the lowest and highest income groups appear to be underrepresented and over-represented, respectively, in the study. A significant proportion of households reported that they supplemented mains water supplies with roof collected rainwater stored in a tank. Approximately 77% of households that responded to the questionnaires and about 53% of the entire cohort used rainwater from tanks for household water supply. The proportion of houses with rainwater tanks is greater than the 32% reported by the QWC. The average results for the houses without rainwater tanks, using rainwater for indoor and outdoor water uses, and for outdoor water uses only are presented in Figure 4.

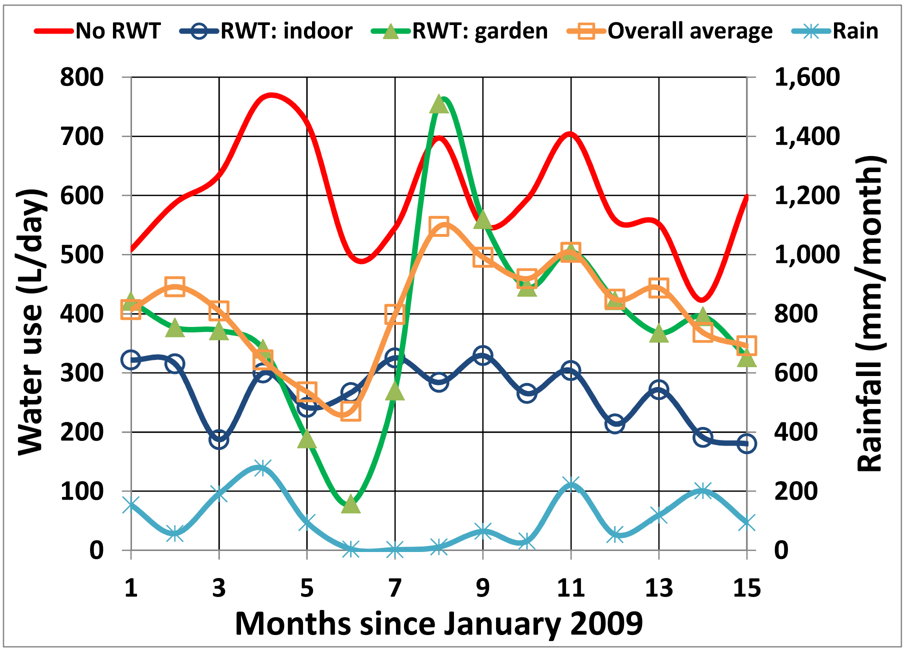

Figure 4: Summary of monitoring results for SEQ

Figure 4 demonstrates that households utilising rainwater for indoor and outdoor water uses, and for outdoor uses only used significantly less mains water than houses without rainwater tanks. The use of rainwater tanks has also reduced the seasonal variability of demands for mains water. This effect was particularly evident for households using rainwater for indoor and outdoor water uses. In addition, Figure 4 shows that the effectiveness of rainwater tanks for reducing mains water use was increased during the last few months of the monitoring period when rainfall returned to more normal patterns. Note that the monitoring period included high level water restrictions until April 2009, medium water restrictions to December 2009 and then permanent water conservation measures thereafter. A summary of the monitoring results for rainwater tanks are provided in Table 2.

Table 2: Summary of monitoring results from SEQ for rainwater tanks

Household rainwater use	Number of houses	Average monthly water use (L/day)			Reduction (%)	Reduction (kL/annum)	Per-capita use (L/day)
		Average	Maximum	Minimum			
No Tanks	17	514	871	278	-	-	139
Indoor	11	268	428	125	48	89.79	63
Outdoor	14	383	725	263	24	47.82	117

Table 2 highlights that 17 households were not connected to rainwater tanks whilst 11 households used rainwater for indoor and outdoor uses and 14 households use rainwater for outdoor water uses. The average reduction in demands for mains water for households utilising rainwater for indoor and outdoor uses, and for outdoor uses was 89.8 and 47.8 kL/annum respectively. The performance of households using rainwater for indoor and outdoor purposes was considerably in excess of the targets in the Queensland Development Code (MP 4.2). The observed average per-capita water use from households without rainwater tanks of 139 Litres/person/day is slightly higher than the per-capita water use reported by the QWC for households during the drought of 131 Litres/person/day as expected. It is significant that the use of rainwater tanks has reduced per-capita water use to 117 and 63 Litres/person/day for outdoor, or indoor and outdoor uses respectively. This result is less than the per-capita water use of 200 Litres/person/day targeted by the SEQ water strategy. The impact of household rainwater harvesting on seasonal demands for mains water is demonstrated in Table 3.

Table 3: Impact of rainwater harvesting on seasonal mains water use throughout SEQ

Household rainwater use	Number of houses	Average monthly water use (L/day)			Reduction (%)	Household size (people)	Per-capita use (L/day)
		Average	Maximum	Minimum			
No tanks	17	514	871	278	-	3.7	139
Outdoor	14	383	725	263	24	3.3	117
Toilet & outdoor	4	296	425	192	42	3.5	84
Laundry & outdoor	2	225	271	130	56	5.5	41
Toilet, laundry & outdoor	5	254	376	121	51	5.2	49

Tables 2 and 3 reveal that the use of rainwater tanks has reduced average, maximum and minimum water uses throughout the monitoring period. This demonstrates the resilience of rainwater tanks for reduction in mains water demands throughout SEQ. In addition, Table 3 shows that the use of rainwater for laundry and outdoor uses, and toilet, laundry and outdoor uses produces the greatest reduction in demands for mains water. The observations of the impacts of different capacities of rainwater tanks in the survey are presented in Table 4.

Table 4: Mains water savings versus capacity of rainwater tanks

Tank size (kL)	Number	Average monthly water use (L/day)		
		Average	Maximum	Minimum
No tank	17	514	871	278
0 - 2	6	248	341	100
2 - 5	8	376	663	198
5 +	11	303	462	153

Table 4 shows that households with capacities of rainwater tanks less than 2 kL generated the lowest demands for mains water. Households with rainwater tanks larger than 5 kL provided the lower demands for mains water than tanks with capacities between 2 and 5 kL, and higher mains water demands than houses with rainwater tanks smaller than 2 kL. This result highlights that the performance of rainwater harvesting is dependent on water use from tank and roof area rather than the size of the rainwater tank. Observations of the impacts of different roof areas connected to rainwater tanks in the survey are presented in Table 5.

Table 5: Impact of roof area connected to rainwater tanks

Connected roof area (m^2)	Number	Average monthly water use (L/day)		
		Average	Maximum	Minimum
No tank	17	514	871	278
< 50	3	388	513	281
50 - 100	6	304	439	79
100 - 150	5	338	492	192
150 - 200	5	292	574	114
>200	6	329	607	143

Table 5 shows that rainwater tanks connected to all roof areas produce significant reductions in demands for mains water. However, rainwater tanks connected to roof areas in the range of 50 m^2 to 100 m^2 and 150 m^2 to 200 m^2 produced lowest demands for mains water. This outcome highlights that the performance of rainwater harvesting is also primarily dependent on water demands from the rainwater tank and that relatively small roof areas can produce significant savings in mains water. Information about peak daily and hourly water use is used to design water distribution infrastructure. The average per-capita peak daily and hourly water uses recording during the monitoring period is provided in Table 6. Table 6 shows that the use of rainwater tanks to supply indoor and outdoor water demands provides substantial reductions in peak hourly and daily water demands. This result indicates that the use of rainwater tanks will reduce impacts on or requirement for local and regional infrastructure including water distribution systems, pumping stations, water treatment plants and pressure reservoirs. It is noteworthy that limiting the use of rainwater to outdoor uses will not produce benefits for local distribution infrastructure.

Table 6: Per-capita peak water uses at households

Category	Peak water use (L/pp/minute)	
	Hour	Day
No tanks	1.64	0.36
Tanks - garden	1.74	0.19
Tanks - indoor	1.07	0.17

The distribution of these results is demonstrated for peak hourly and daily mains water demands in Figures 5 and 6 respectively.

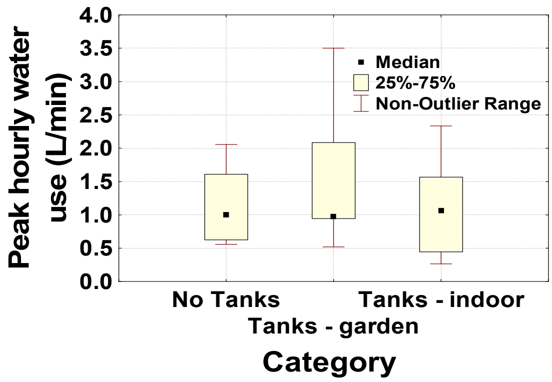

Figure 5: Per-capita peak hourly use

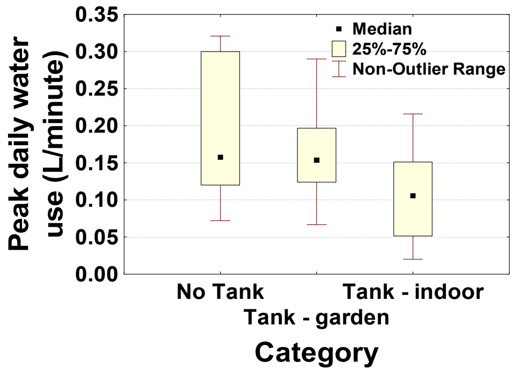

Figure 6: Per-capita peak daily use

Figure 5 shows that the median values of per-capita peak hourly water use at households with and without rainwater tanks are similar. However, use of rainwater tanks for only garden watering shows a trend to increases peak hourly water use and the use of tanks for indoor uses show a significant trend to decreases in peak hourly water use. Figure 6 reveals the use of rainwater tanks for indoor water uses significantly reduces peak daily water demands. Use of rainwater tanks for indoor uses will reduce impacts on water distribution, or requirement for, treatment and storage infrastructure. The reported frequency of toilet flushing, showering, clothes washing and washing dishes is presented in Table 7.

Table 7: Frequency of appliance use in households

Criteria	Frequency (events per week)				
	0 - 5	5 - 10	10 - 15	15 - 20	20+
Toilet (flushes/person)	1	6	7	4	8
Shower (Showers/person)	6	18	1	-	-
Clothes Washer (Loads)	12	10	4	-	-
Dish Washer (Loads)	10	8	5	1	3

Table 7 shows considerable variation in the frequency of appliance use in households. The frequency of toilet flushing has the greatest range of responses which may represent a higher impact of household behaviour on this end use – if residents are away from home at work or other activities the frequency of flushing will be less whilst those at home with (say) children will generate a higher frequency of toilet flushing. The frequencies of showering and clothes washing displayed significantly less variance with the majority of households experiencing up to 10 showering events per person and up to 10 clothes washing events each week. The washing of dishes showed a greater range of frequencies which displays household use of dish washers rather than washing dishes by any method.

The frequency of shower use is compared to household size and household water use in Figures 7 and 8 respectively.

Figure 7 shows that the frequency of per-capita shower use decreases for household sizes greater than two people. Figure 8 reveals that household water use increases with increased frequency of shower use. The frequency of toilet flushing is compared to household size and household water use in Figures 9 and 10 respectively.

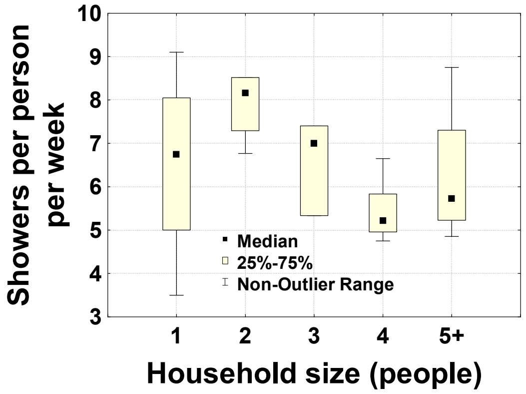

Figure 7: Frequency of shower use versus household size

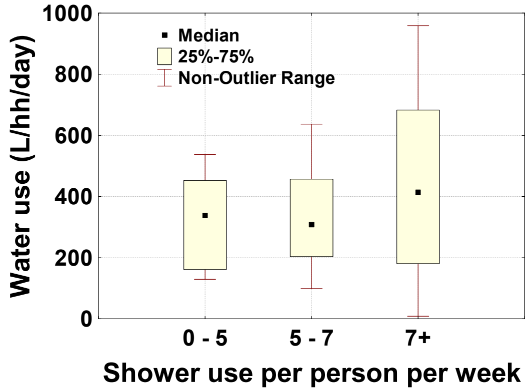

Figure 8: Household water use versus frequency of shower use

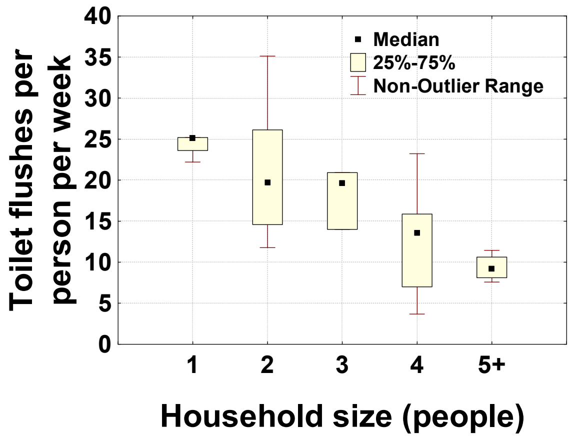

Figure 9: Frequency of toilet flushing versus household size

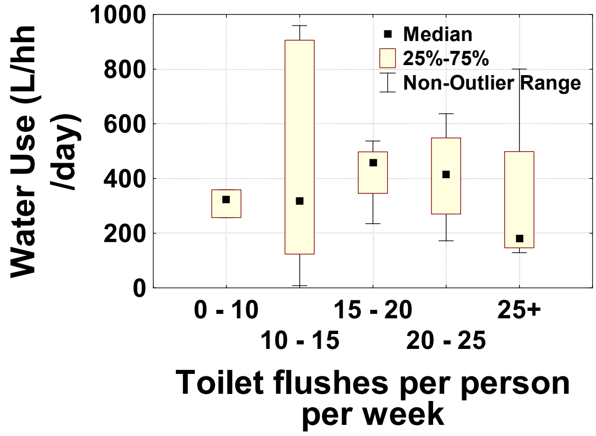

Figure 10: Household water use versus frequency of toilet flushing

Figure 9 shows that the frequency of per-capita toilet flushing decreases with increases in household size. Figure 3.10 reveals that household water use increases with more frequent toilet flushing up to 20 flushes per person per week. Household water use declines with increases in frequency of toilet flushing greater than 20 flushes per person per week. The frequency of washing dishes is compared to household size and household water use in Figures 11 and 12 respectively. Figure 11 shows that the frequency of washing dishes increases with household size up to a three person households. Figure 12 reveals that household water use is relatively independent of the frequency of washing dishes. Household water use is greater from frequencies of dish washing greater than 15 loads.

Figure 11: Frequency of washing dishes versus household size

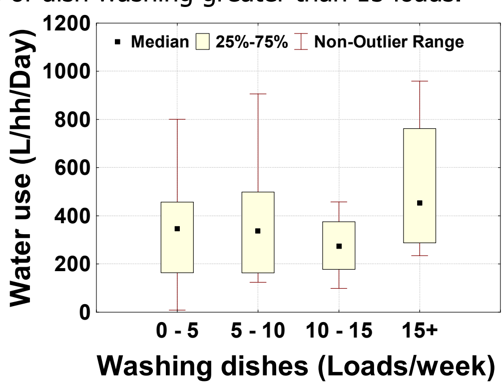

Figure 12: Household water use versus frequency of washing dishes

The frequency of washing dishes is compared to household size and household water use in Figures 13 and 14 respectively. Figure 13 shows that the frequency of washing clothes increases with household size and that two person households have a higher frequency of clothes washing than 1, 3 and 4 person households. Figure 14 reveals that household water use increases with more frequent clothes washing up to 7 loads per week and declines thereafter.

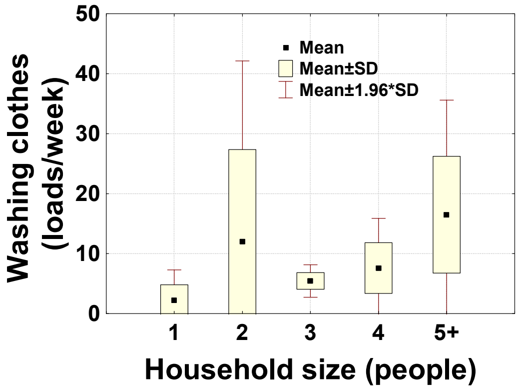

Figure 13: Frequency of clothes washing versus household size

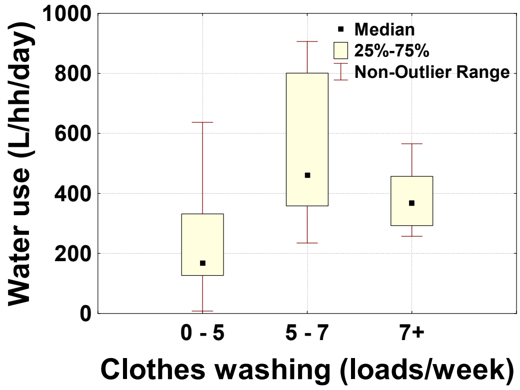

Figure 14: Household water use versus frequency of clothes washing

4. CONCLUSIONS

The water use behaviour of households throughout South East Queensland was monitored using mini smart meters during the period February 2009 to May 2010. Audits were also completed to accurately define the characteristics of each household. Each household also completed a water use diary. Metering results were combined with responses to questionnaires and water use diaries to develop an understanding of water-use behaviours throughout the SEQ region. The size of the residential sample was relatively small. However, the length and multiple processes involved in the monitoring allowed a range of insights from the study. Residential water use was observed to be dependent on household size. However, increases in per-capita residential water uses were seen to diminish with increased household size. The relationship between per-capita water use and household size has a non-linear form. A non-linear relationship was also observed between household income ($/annum) and household or per-capita water use. Increases in household income were related to small increases in per-capita water demands and increases in household size. Households with higher incomes were more likely to have water efficient appliances and rainwater tanks. This result explained the small increases in per-capita and household water demands associated with households with higher incomes. Per-capita water use was found to be strongly dependent on the reported frequency of showering.

Households without rainwater tanks had an average daily mains water demand of 514 litres and a per-capita daily demand of 139 litres. Households using rainwater for outdoor use only had an average daily mains water demand of 383 litres and a per-capita daily demand of 117 litres – annual savings of 47.8 kL. Households using rainwater for indoor and outdoor uses had an average daily mains water use of 268 litres and a per-capita demand of 63 litres – annual savings of 89.8 kL. The performance of households using rainwater for indoor and outdoor uses exceeded the requirements of Queensland Development Code MP 4.2. Relatively small rainwater tanks (2 kL) and roof areas (50 m^2 to 100 m^2) generated the largest reductions in mains water use. Use of rainwater for indoor uses reduced peak daily and hourly mains water demands which is expected to diminish impacts on and requirement for water distribution, pumping and treatment infrastructure.

5. ACKNOWLEDGEMENTS

This project benefitted from dedicated contributions of Josh Bairstow and Andrea McGrath, and from the reviewers. The support of the QWC and Synergies Economics is gratefully acknowledged.

6. REFERENCES

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