Rainwater tank monitoring report

A 12-month one-minute interval data study of rainwater tank water savings and energy use for 52 real life installations

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Executive Summary

The sustainability of rainwater tanks as a water solution for large cities depends on their ability to save water while using minimal energy. In the largest detailed rainwater tank monitoring study in Australia to date, Sydney Water remotely monitored rainwater tank water and energy use for more than 12 months for 52 real-life installations at one-minute intervals.

Monitored households were newly built households, on average two years old, that had installed rainwater tanks as part of compliance with NSW's BASIX water regulation requirements. These households were located from all over the Sydney basin.

The study's principal objectives were to confirm that rainwater tanks in real life installations save water as expected and if they were not, to identify opportunities to further increase water savings and reduce their pumping energy use.

The monitored households saved an average of 21% of their total household water demand due to the rainwater tanks, which equates to around 38 kL per household per year of water savings. The rainwater tanks were effective because of their configuration: large tank sizes to collect the rainfall, on average 4,200L; large roof areas to collect the rain, on average 210m^2; and high connection rates to outdoor taps, washing machines and toilets to use the rainwater, with a demand of 59 kL per household per year.

Rainwater tanks still performed well even though the households had highly efficient internal water using fixtures and appliances, typically with 4.5/3L toilets and efficient washing machines that use 60 to 80 L a wash. These efficiencies reduced the demand for rainwater. The rainwater tanks also performed well despite lower than average rainfall during the monitoring period, which reduced the rainwater available for use.

Energy use from the rainwater tank was relatively low at a household level, with a median energy use of 62 kWh per household per year (ie approximately $15 a year). The median energy intensity, which is the energy used per unit of rainwater used, was 1.48 kWh/kL. This compares favourably with desalination, is close to recycled water and is worse than average surface water supply (eg dams) energy intensity, but may be better for the more efficiently designed rainwater tank pump systems.

The study identified and quantified a number of practical options to improve the efficiency of rainwater tanks by ensuring water savings are maximised and energy is used efficiently.

On an individual household basis, tank configuration needs to be improved to increase water savings. Tank configuration could be improved by maximising tank capacity, increasing roof area connected and ensuring tanks are connected and used for all outdoor and washing machine uses. A number of households did not achieve regulatory compliance for tank configuration (ie a smaller tank size than required), with modelling showing that this decreased water savings by more than 18 kL per year in some instances.

To improve energy performance, monitoring has shown that correct rainwater pump selection is critical. Based on the demand profile of the sample, pump choice alone had the potential to vary average intensity from 0.68 kWh per kL to 2.4 kWh per kL, depending if all households chose the best performing or worst performing pump respectively.

Pumps were found to perform less energy efficiently as flow rate decreases. Rainwater demand was found to be primarily for low water use events (eg toilets and washing machines uses) that have a low flow rate, with a median flow of 5 L in a minute. At this low pump flow rate, the pumps in the study achieved an average energy intensity of 1.5 kWh/kL. The pumps operated at a significantly lower energy intensity at high flow rates (ie above 15 L in a minute), approximately 0.7 kWh per kL, but these high flow rates only accounted for 2% of the demand.

In response, pumps need to be selected (if available) or designed such that they operate efficiently at low flow rates, particularly below 10 L per minute. The addition of pressure tanks to the pump set-up may further improve low flow rate energy efficiency, as was shown for two properties in the study.

To complement better installations practices, householders need to be better informed about simple steps they can take to improve the effectiveness of their tanks during operation. In particular, advice on reducing leaks in the rainwater tank system (eg leaking toilets) would reduce the occurrence of households with high dormant energy use (ie energy use not associated with a monitored water use).

The monitoring shows that the while rainwater tanks are already successfully achieving water savings, there are a number of easy practical steps that installers/builders can take to improve the overall sustainability of rainwater tank use

A sustainable tank system is one that is easy for householders to use and maintain if properly configured. It needs to be configured to maximise the potential for rainwater use by connecting as many end uses as possible and connecting as much roof area as possible. The tank needs to be sized according to these outcomes. Using pumps that are energy efficient at low flow rates, possibly complemented with pressure tanks, can reduce energy use. Simple information needs to be available to customers to reduce the risk of easy losses (eg alarms about leaks that increase energy use).

This type of system would increase average water savings and reduce rainwater tank pump's energy intensity to better than surface water supplies in some cases. Even with these improvements, rainwater tank installations would remain a relatively expensive water source with their levelised cost typically between $4 a kL and $8 a kL.

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1 Context

In 2004 the NSW Government introduced BASIX, the Building Sustainability Index, a key planning policy requiring all new houses and units to be designed to use less potable water and emit fewer greenhouse gases. Reduction targets of 40% less water use and 40% fewer greenhouse gas emissions than the average NSW dwelling were set by BASIX.

BASIX was introduced in stages, commencing on 1 July 2004 for single dwellings in Sydney. In 2005, all single dwellings and multi-unit dwellings in NSW were incorporated into the scheme, and in 2006, BASIX was expanded to include renovations.

Each household that complies with BASIX receives a customised BASIX certificate. This certificate outlines the requirements the household has to achieve to comply with the regulation. Examples of requirements include installing a toilet of minimum water efficiency (ie minimum water star rating), installing a tank of a certain size, and connecting certain end uses (eg toilets and washing machines) to the rainwater tank.

Due to regulations such as BASIX, more and more new homes are integrating alternative water supplies into their design. Rainwater tanks are by far the most common alternative water supply option selected. No households in this analysis connected their rainwater tank to the whole of household.

The performance of urban rainwater tanks is largely unknown, particularly for those with internal connections (i.e. washing machines and toilets). There have only been a small number of studies to date verifying operational performance and these have mainly focused on water savings. The energy demand of rainwater tanks is fast becoming a focus of research agendas.

Major previous rainwater tank studies include:

- The Institute for Sustainable Futures (Retamal, 2009) monitored the energy and water use of 8 household rainwater tank systems in Sydney and Newcastle for a period of 2 weeks to determine the energy intensity. The study found that a typical rainwater system supplying toilet, laundry and garden had an energy intensity to be approximately 1.5kWh/kL. Significant variation was found between the houses depending on the appliance water efficiency and household water usage. Pumps were found to work more efficiently at higher flow rates.
- A study carried in Brisbane (Beal et al, 2008) on a 22 lot water sensitive subdivision, found that the rainwater systems increased the energy usage of each lot compared to a conventional centralised system. The average energy intensity of the subdivision, that uses a combined individual and communal rainwater tank system, was approximately 3kWh/kL. System configuration and pump efficiency had the most effect on energy usage and resident behaviour was a confounding factor.
- A South East Water study (AWA, 2009) on 31 residences with rainwater tanks included monitoring of both rainwater savings and energy demand of 11 of these tanks by the minute. The other 20 residences monitored rainwater usage by the minute but only recorded the total energy usage over the monitoring period. This study found a median specific energy intensity of 1.98kWh/kL.

Sydney Water identified a significant knowledge gap in existing research that justified the need for an intensive monitoring project. Existing studies were found to have very small sample sizes and short monitoring periods. The impact of different local rainwater tank design, locations and community awareness also limited the value of existing studies for Sydney Water. In particular, the majority of the systems monitored in previous studies installed rainwater tanks voluntarily, not as part of a regulatory obligation.

2 Approach

To assess the overall sustainability of rainwater tanks as a water source, it is important to understand the benefits and impacts of these systems relative to other water sources. This study concentrates on two elements:

- What water savings are achieved from a rainwater tank (key benefit)
- What energy is consumed in achieving this benefit – the energy intensity (key impact)

The analysis also aims to understand why and how water savings are achieved and to identify how energy use would best be optimised in real-life case studies.

To achieve this, Sydney Water monitored rainwater tank energy and water use for 52 households. To ensure consistency with real-life applications of rainwater tanks, all of these households were recruited from newly built homes that had opted to install a rainwater tank in order to achieve the water-savings target mandated in the Department of Planning & Infrastructure's BASIX program.

The rainwater tank monitoring sample was selected from the BASIX certificate database. A letter explaining the project was sent out to approximately 5,000 households that, according to the BASIX certificate information, required a rainwater tank to comply with BASIX. The sample was recruited using a phone survey and a $50 voucher was provided to the participating households to encourage program take-up.

The rainwater tank monitoring locations were spread all over the Sydney basin (refer Figure 1). The study was designed to capture the broad range of climatic conditions that are experienced in Sydney Water’s area of operation, including the higher rainfall (coastal areas) and lower rainfall (western Sydney). The only area within Sydney Water’s area of operation that was not included in the monitoring locations was the Illawarra. The Illawarra was excluded due to the time required to travel to the monitoring sites. Rainfall in the Illawarra is high and tanks are assumed to perform favourably in this area. However, this has not been verified through this research and is beyond the scope of this report.

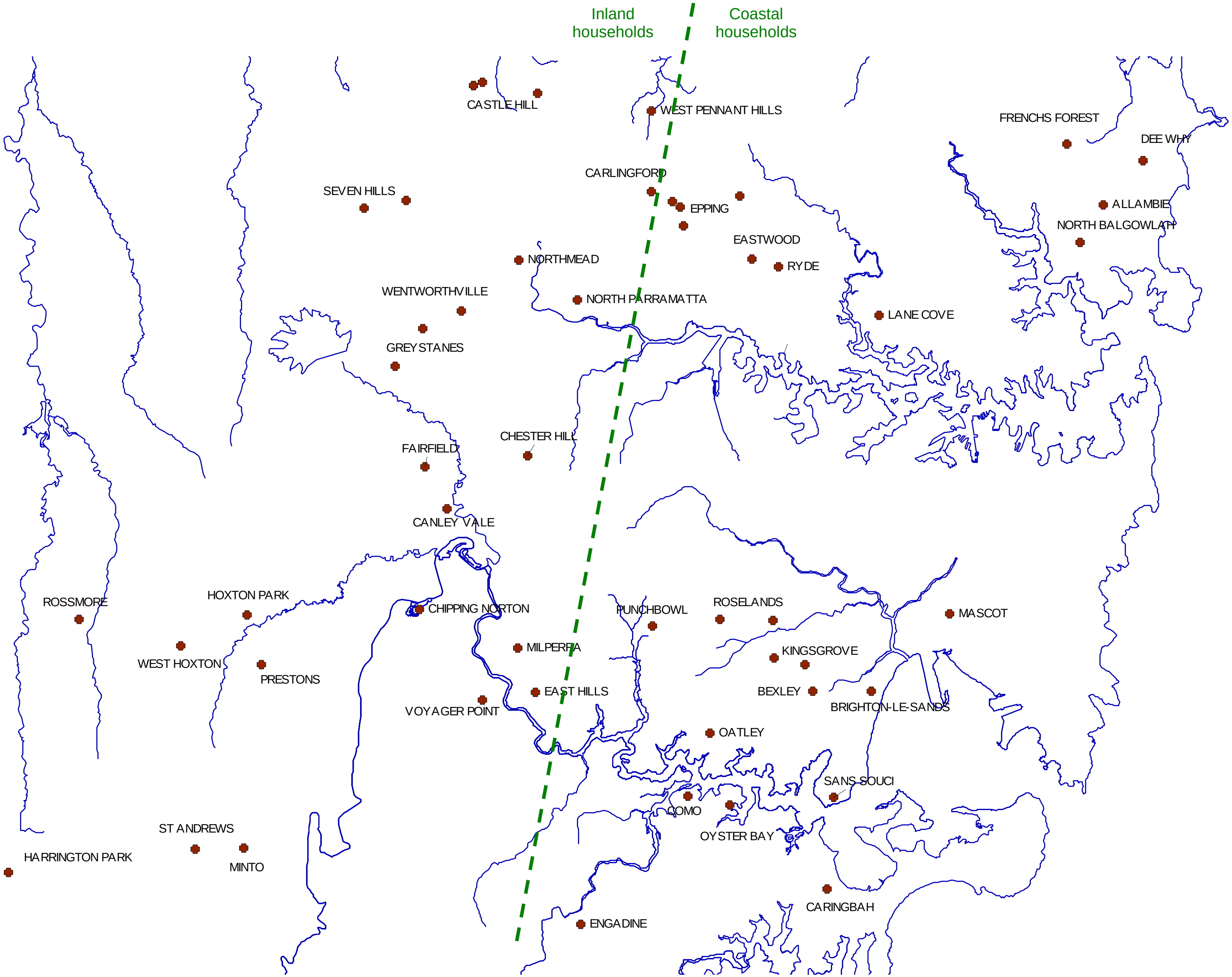

Figure 1 Location of monitoring sites (including the split between inland and coastal households – refer section 3.3.6)

2.1 Monitoring set-up

Each rainwater tank monitoring system was set-up as follows:

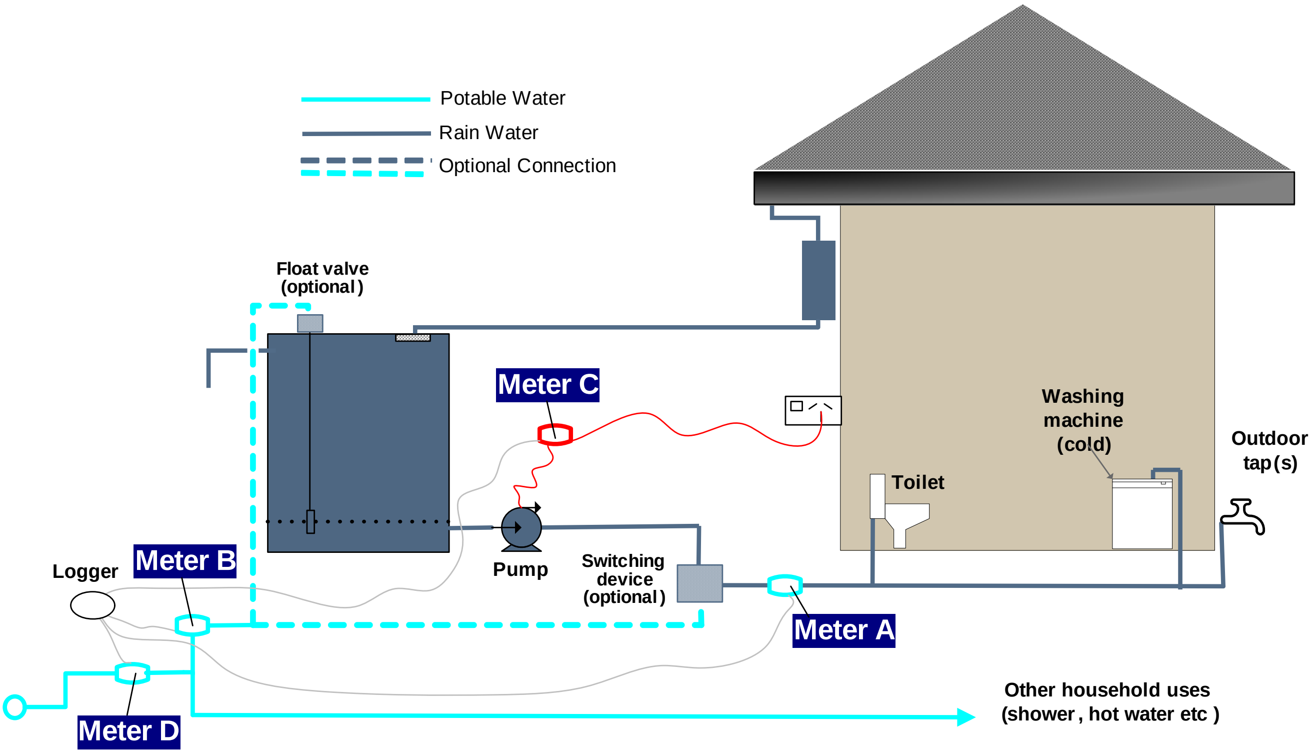

Figure 2: Typical rainwater tank set-up with location of metering

That is, data was collected for:

- Meter A - Water demand from the rainwater tank system for connected uses (for details of connected uses refer section 2.3.1 – note that all tanks in the study were used for non-drinking water end uses only)
- Meter B - Water demand from the potable top-up system
- Meter C - Energy demand from the pump connected to the system, ie pumping only rainwater with switching devices or both rainwater and potable top-up for float systems
- Meter D - Mains demand including all household potable demand and rainwater tank top-up.

Data was logged at one-minute intervals and remotely sent to a database periodically. Water was collected in 0.5L pulses and energy in 1Wh packets. An example real-life set-up is shown in Figure 3.

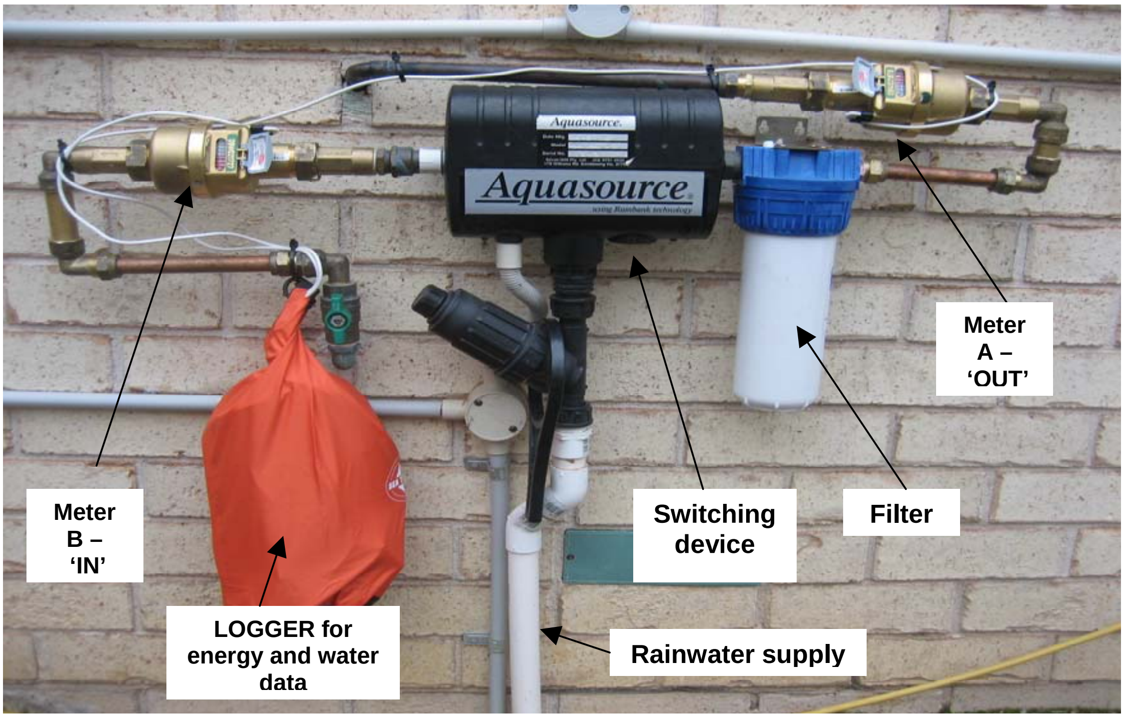

Figure 3: Example on-site set-up of monitoring equipment (not shown – the energy meter C and the mains meter D)

An example of the rainwater water and energy data produced for a household is shown in Figure 4 using the logger set-up shown above for a household with an automatic switching device. This graph consists of the:

- Green line – aggregated daily energy use by the pump, shown in Wh per day, based on one minute interval 1Wh pulse data from Meter D.
- Stacked orange columns - aggregated daily top-up potable water use by the rainwater tank connected end uses, shown in L per day, which is based on one minute interval 0.5L pulse data from Meter B. Top-up occurs when there is no available rainwater in the tank and supply instead comes from the mains potable water supply. An example period of top-up only use is in November.
- Blue columns – aggregated daily rainwater use by rainwater tank connected end use, shown in L per day. This data is based on one minute interval 0.5L pulse data from Meter A minus any one minute interval 0.5L pulse data from Meter B for the same period. Rainwater use occurs where there is sufficient supply in the tank from rainwater that is collected from rainfall events.

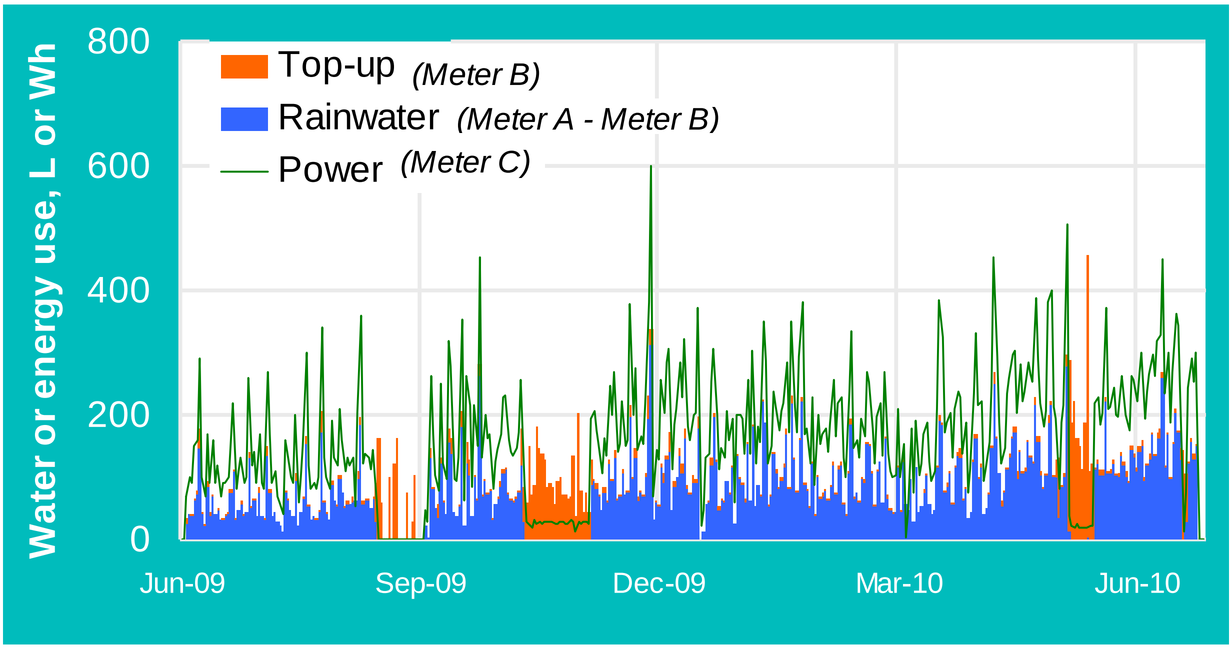

Figure 4 Example aggregated daily demand for a household showing top-up demand, rainwater demand and power demand by day

An example of the rainwater water and energy data produced for a household is shown in Figure 5 using the logger set-up shown above. This graph consists of the:

- Dark blue columns – aggregated daily mains potable water use by the household, shown in L per day, which is based on one minute interval 0.5L pulse data from Meter D. Household mains water use includes all non-rainwater tank connected household demands (eg showers, kitchen taps) and any top-up demand for the rainwater tank.

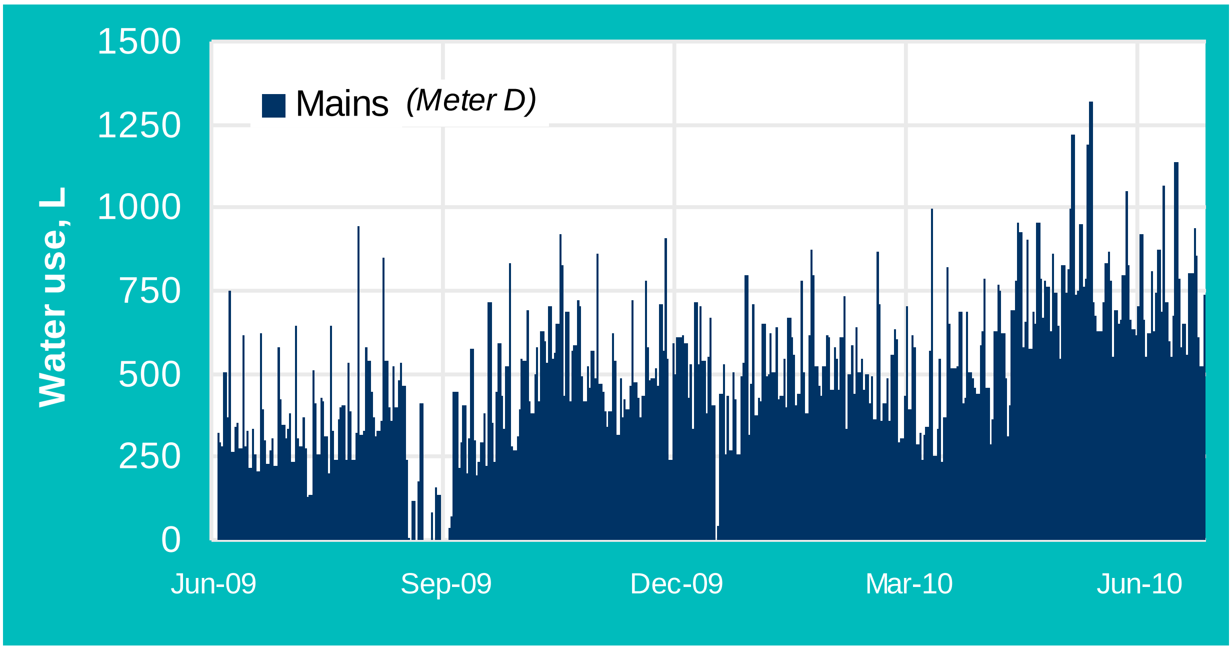

Figure 5 Example aggregated daily demand for a household showing mains demand

Households were monitored for more than 12 months with the period of assessment being from 1 July 2009 to 30 June 2010. Where data did not exist for the full 12 months, such as due to logger failure, shorter periods were analysed (with a minimum of 117 days). All results were converted to an equivalent year saving.

Data retrieved for 8 households were unable to be assessed for any of the monitoring outputs due to a mixture of incorrect logging set-up, continuous logging failure, or tank failure.

Site inspections also collected information on rainwater tank configuration, connections, technology type, maintenance practices and any issues the homeowner has experienced with the tank. The additional site inspection results along with the detailed rainwater tank monitoring have provided substantial information to enable an assessment of the tank performance.

2.2 Household characteristics

The following sections summarise the key known characteristics for households in the rainwater tank monitoring study.

2.2.1 Household type

All households were owner-occupied detached dwellings that had opted to use rainwater tanks in order to achieve the water savings mandated under the BASIX program. The study specifically targeted this household type.

2.2.2 Age of homes

The majority of homes in the study were occupied in 2007 and 2008 as shown in Table 1. On average, the houses had been occupied for approximately 2 years at the start of the monitoring study (July 2009).

Table 1: Build year for households

	2004	2005	2006	2007	2008
Number of houses built	1	5	7	21	18

2.2.3 Property size

The median property size for the households was 630 m^2. The majority of households were either in the 400 to 600 m^2 property size range or the 600 to 800 m^2 range.

The distribution of the property sizes is shown below in Table 2.

Table 2: Distribution of households by property size

	Property size range					
	0 to 200m^2	201 to 400m^2	400 to 600m^2	600 to 800m^2	801 to 1000m^2	More than 1000m^2
No of households	0	1	21	24	2	4

2.2.4 Number of bedrooms in households

The majority of the homes in the study were 4 bedroom houses. This is consistent with house sizes for new homes generally being larger than the broader community.

Table 3: Number of bedrooms in each household

	Number of bedrooms[1]				
	2	3	4	5	6
No of households	0	12	31	5	1

1 No data was available for three households

2.2.5 Occupancy rate

Average occupancy rate from the survey of households in the study was 3.55. Occupancy rate is shown in Table 4.

Table 4: Survey results - occupancy rate of households

	Occupancy					
	1	2	3	4	5	6
No of households	2	11	11	16	8	4

The high occupancy rate for the households in the study reflects that the households are newly built homes with high numbers of bedrooms.

2.3 Rainwater tank set-up characteristics

The following sections discuss the main rainwater tank set-up characteristics for the households.

Where available, the rainwater tank monitoring sample has been compared to the larger site inspection samples (referred to as the survey sample).

2.3.1 Tank size and roof area connected

Information regarding tank size and roof area connected is discussed in section 3.3.

2.3.2 Rainwater tank connections (connected uses)

To meet the NSW BASIX regulation for water efficiency, the majority of single households connected their rainwater tank to supply the toilet, washing machine and outdoor demand. The majority of households connected 2 or 3 toilets. The importance of connection is discussed further in Section 3.3.4.

Table 5: Rainwater tank connected uses for the monitoring sample and broader survey sample

Connection type	Monitoring sample		Survey sample	
	%	n	%	n
Garden	100%	52	94%	418
Toilet	92%	48	92%	424
Washing machine	65%	34	62%	275

Also, ten households within the monitoring study were identified to have pools of average capacity 40,000L.

2.3.3 Types of mains top-up methods for rainwater tanks

There are two types of top-up systems commonly available to supply mains potable water when rainwater is not available– a switching system or a float (or trickle-top) system. Some systems are manually topped up if required.

For a switching system, an automatic mains switching device system supplies water from mains when the rainwater tank reaches a set minimum level or the pump fails. At all other times, water is supplied directly from the rainwater tank, usually using a pump. Supply is diverted using a 'rainwater tank control valve'. Therefore when the rainwater is not being used the home is supplied with mains water directly from the system independent of the rainwater tank.

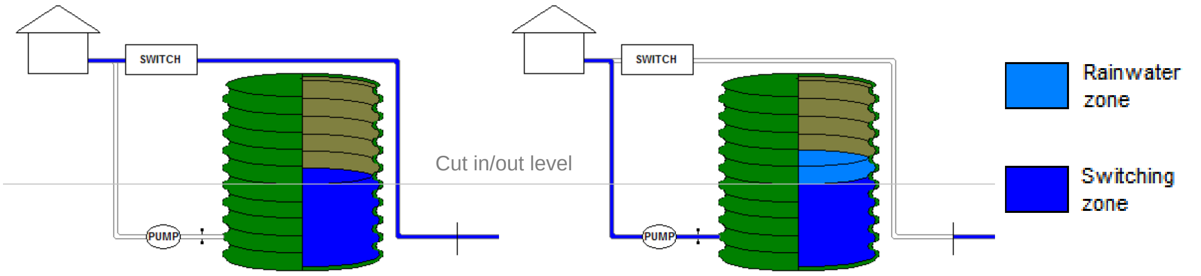

Figure 6: Automatic mains switching device system set-up (flow switched to mains when reaches switching zone (L) and pumping when above switching zone (R))

For a float system, a trickle system supplies mains water through a flow-controlled valve into the rainwater tank when there is inadequate rainwater available. That is, when the water level drops below the cut in level, the valve opens and a trickle of water feeds into the tank. The trickle feed continues until it reaches the cut out level when the valve closes. Storage above the cut in/out level is available for rainwater collection. All water is supplied to the household from the tank usually using a pump.

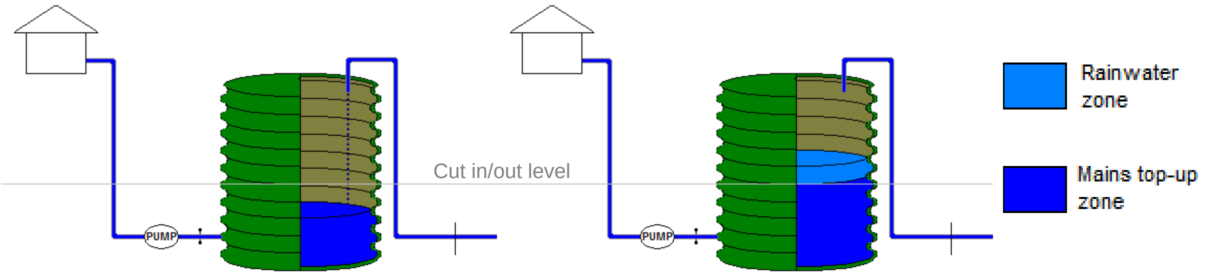

Figure 7: Trickle top-up system set-up (trickle top-up occurs when within top-up zone (L) and no trickle top-up when in rainwater zone (R) with pumping at all times)

The study found that automatic switching devices are by far the most common installation in new homes (refer Table 6).

Table 6: Top-up systems used to provide mains waters when rainwater is not available

Connection type	Monitoring sample		Survey sample	
	%	n	%	n
Switch	90%	47	87%	327

Float (trickle top-up)	6%	3	4%	13
None or other	4%	2	9%	34

2.3.4 Tank configuration

2.3.4.1 First flush device

Approximately 80% of households had first flush devices (40 out of 52 households), with an average first flush volume of 10L.

2.3.4.2 Water filters

A surprising high number of households (46% - 24 out of 52 households) had water filters for their rainwater supply. This is despite the rainwater tanks only being connected to non-potable uses.

2.3.4.3 Number of tanks

The majority of households had a single tank as seen in Table 7. Some households had multiple rainwater tanks that were either co-located or distributed around the property.

Table 7: Number of tanks per household

	Number of tanks			
	1	2	3	4
No of households	40	10	1	1

2.3.5 Tank and pump location

Table 8 shows the locations of the tank and pumps for the households.

All tanks in the monitoring study were surface tanks due to the monitoring difficultly related to underground tanks. In the broader survey sample, 18% of tanks were underground tanks.

For tanks in the monitoring study, the pumps were identified as either submersed (eg submersible pump inside the rainwater tank in the water) or above ground (eg pumps that sit outside the tank, usually alongside the tank). The monitoring study shows a higher proportion of submersed pumps than the broader sample.

Table 8: Tank and pump location for the households

Tank location	Pump location	Monitoring sample		Survey sample	
		%	n	%	n
Surface	Above ground	35%	18	33%	130
	Submersed	65%	34	49%	190
Underground	Unknown	0%	0	18%	71

3 Results: Water use

3.1 Demand for water from the rainwater tank and total household demand

Total demand for water from rainwater tank connected uses and total household demand was:

	Sample size (n)	Median	Mean	Minimum	Maximum
Demand for water from the tank, kL/year	40	57	59	5	161
Household demand for all uses, kL/year	40	180	197	84	556

An average household demand of 197 kL/year compares closely with total household demands for new homes constructed under the BASIX regulation. Previous *BASIX Monitoring* studies have shown household demand to be 192 kL/year (2007-08 Report, sample size = 837) and 201 kL/year (2008-09 Report, sample size = 1392).

As a percentage of total household demand this was

	n	Median	Mean	Minimum	Maximum
Demand for water from the rainwater tank as a % of total household demand	40	30%	30%	3%	54%

3.2 Water saved by rainwater use

As rainwater tanks do not have a continuous supply of rainwater, tanks are topped up with potable water from the mains. This means that water savings will be lower than the total demand from the tank.

Water saved by rainwater use was:

	n	Median	Mean	Minimum	Maximum
Water saved by rainwater use, kL/year	46	39	38	0	96

Note: 2 sites included had apparent tank failure during the entire analysis period (ie no water savings)

Water savings (rainwater use) as a % of total household mains demand for operating tanks was:

	n	Median	Mean	Minimum	Maximum
Rainwater use % of total household demand	40	21%	21%	1%	40%

3.3 Discussion of identified factors that influence water savings

Water savings are highly variable due to the number of factors that influence how rainwater tanks operate. These factors include:

- Rainfall and location
- Roof area connected
- Available tank capacity
- End uses connected
- Seasonal demands
- Regional differences

These factors are now discussed in the following sections.

3.3.1 Rainfall and location

Rainfall during 2009-10 in eastern Sydney (~830mm for Sydney Airport) was lower than the longer-term average (~1040mm between 1981 and 2009). Rainfall was also lower in western Sydney (~620mm for Camden) than the longer-term average (750mm between 1981 and 2009).

As seen in Figure 8, rainfall in 2009-10 was sporadic with high rainfall months surrounded by relatively dry months.

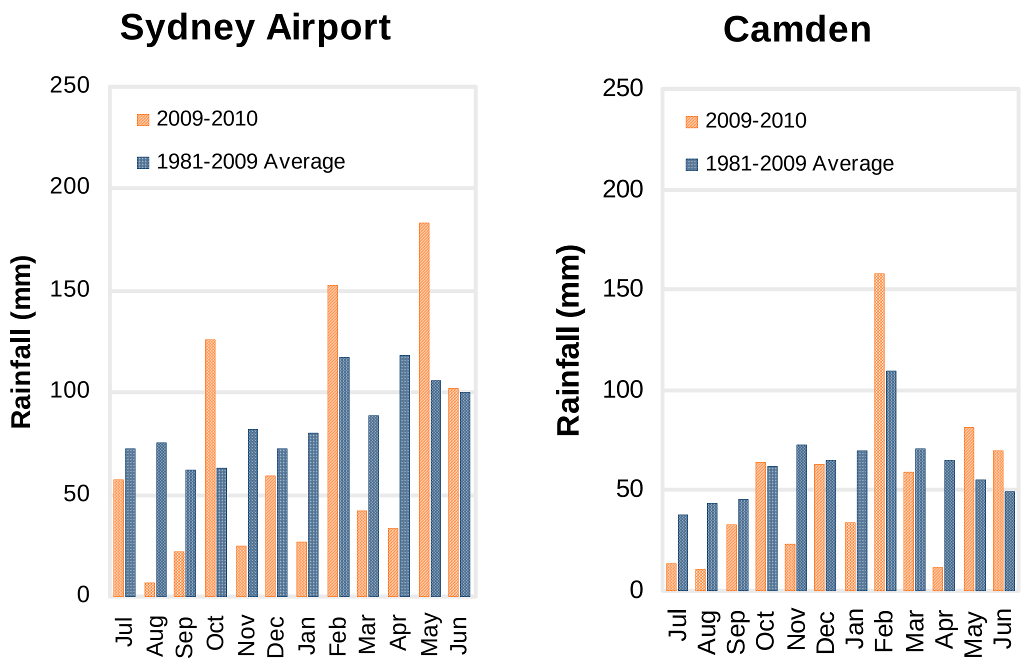

Figure 8: Monthly rainfall comparison for eastern Sydney (Sydney Airport weather station) and western Sydney (Camden weather station)

For small to moderate users, although average rainfall is lower than usual, their savings are likely to be close to the long-term average as they would empty their tanks slowly possibly bridging the gap between rainfall events. For larger rainwater users, their tanks will empty more quickly meaning that their savings might be lower than what is expected in the long term.

Case study: The effect of low rainfall on different households

Figure 9 shows the effect of a low rainfall period on two households with similar sized tanks and roof areas within the study, by modelling volume in the tank using their household demand profiles and local rainfall data for each household.

Household 1 has high rainwater tank connected demand, while household 2 has a much lower demand.

If there were to be a higher rainfall period, household 1 would likely increase their rainwater use, as their tank would be empty less often. A high rainfall period would have no effect on the second household's water savings, as their demand never emptied their tank.

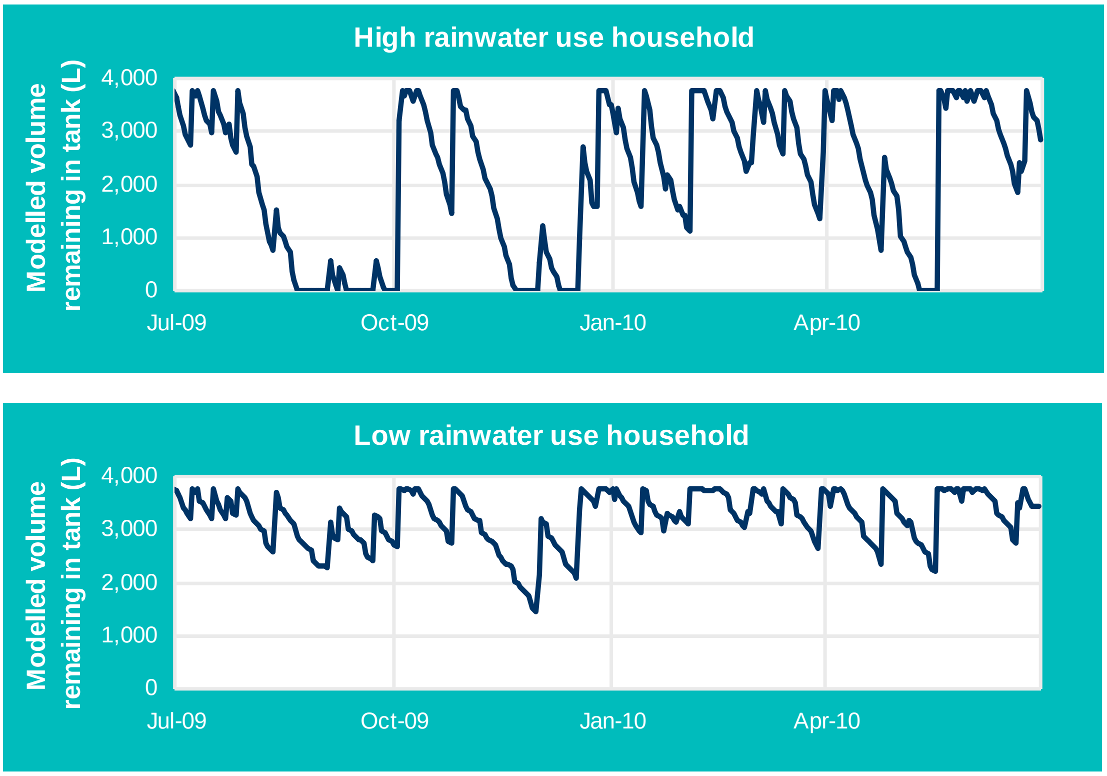

Figure 9: Modelled volume remaining in tank comparing a high rainwater demand household 1 (top) and low rainwater demand household 2 (bottom)

3.3.2 Roof area connected

The greater the roof area connected to a tank, the more quickly the tank will fill in a rainfall event. For example, a rainfall event of 10 mm will fill a rainwater tank with a roof area of 100 m^2 by approximately 800 L (assuming the first 2mm is lost). Increasing roof area connected to 250 m^2 will increase this volume to 2,000 L and will fill the tank more quickly.

The average roof area connected to tanks was determined by the field study to be approximately 210 m^2. This average roof area is close to that specified on the BASIX certificates.

On an individual household basis, compliance with roof area connected on the certificate varied significantly. Some households connected much lower and some significantly more than stated on the certificate.

The average connected roof area of 210 m^2 is likely to be much higher than is typically connected for a rainwater tank retrofitted to an existing household. Retrofitted tanks are typically voluntarily installed as part of a rainwater tank rebate program.

Case study: Roof area connection needs to be maximised to increase rainwater capture

A household had a tank of volume 5,000 L with roof area connected of approximately 140 m^2. The household was a high water user with a rainwater-connected demand of 161 kL per year and a total household demand of 556 kL per year.

Using the demands from the tank and local rainfall data to determine volume, modelling[1] suggests that water savings should have been approximately 69 kL per year.

A roof area connection of 140 m^2 is significantly lower than the average. By remodelling the results using the average roof area connection of 210 m^2, the potential savings from the tank would increase to 81 kL per year, an increase of 12 kL of potential water savings a year.

3.3.3 Available tank capacity

The larger the storage volume in the rainwater tank, the greater the capacity is available to store rainwater and therefore this creates a higher potential for water savings.

Average tank size for the sample from the field study was approximately 4,200 L, which was slightly higher than listed on their BASIX certificates of 3,650 L.

The available capacity in the tank can be reduced when the top-up level in the tank is set higher than required. Typically, a small amount of 'dead space' is allocated in tanks so that poorer quality water at the bottom of the tank, due to the settling of solids, is not extracted for use. To allow for this 'dead space', top-up levels are typically set slightly higher than the bottom of the tank. If the level is set too high, rainwater can be wasted.

Modelling of tank performance appeared to indicate that the amount of 'dead space' typically found in tanks is low although there were a couple of properties where the modelled tank performance did not match with actual performance, indicating that tank top-up levels were not set optimally.

Case study: Tank capacity needs to be maximised by setting an appropriate tank top-up level

A household had a tank of volume 3,000 L with roof area connected of approximately 250 m^2. Over the analysis period, the household saved 27,500 L of water.

Using the demands from the tank and local rainfall data to determine volume, modelling suggests that water savings should have been significantly higher, approximately 45,000 L.

Recalibrating the model so that the modelled savings matches the actual savings requires effective tank volume to be reduced to only 30%,or approximately 900 L of available tank space.

It is likely that this household has had their top-up set to a level higher than required, meaning that their tank use is less effective and reducing their savings by approximately 18,000 L.

3.3.4 End use connection extent and use

The greater the number of end uses connected to a rainwater tank, the higher the demand will be and therefore there is an increased potential for water savings. For detailed information about connections, refer to Section 2.2.

[1] Modelling assumes 10% dead space for rainwater tank volume, rainfall loss for the first 2mm of any rainfall event due to evaporations and losses with full roof area connection. It is based on the demand profile for the household during the monitoring period.

The BASIX program allows the applicant to select a range of end uses to be connected to rainwater tanks. Estimated water savings from the rainwater tank connections depend on a number of factors such as household size, garden size and efficiency of end uses.

In the study, a number of households were identified that were not achieving their full water saving potential due to either end uses not being connected as required by their BASIX certificate, for example toilet, washing machine and/or outdoor demands from their mains demand, or not being used, for example switching their tank off during washing machine uses.

Case study: The importance of connecting as many uses as possible to the tanks

The household in this case study was required to connect three toilets and their washing machine. In addition, all households in the study were required to connect at least one outdoor tap to their rainwater tank.

In reality, the demand profile for this household shows that it has toilet connections and a connection to the washing machine. Figure 10 shows a daily baseline water demand of between 50 and 100 L for toilet flushing, with the regular weekly washing machine use. There is no significant outdoor/seasonal demand in the demand profile from the rainwater tank.

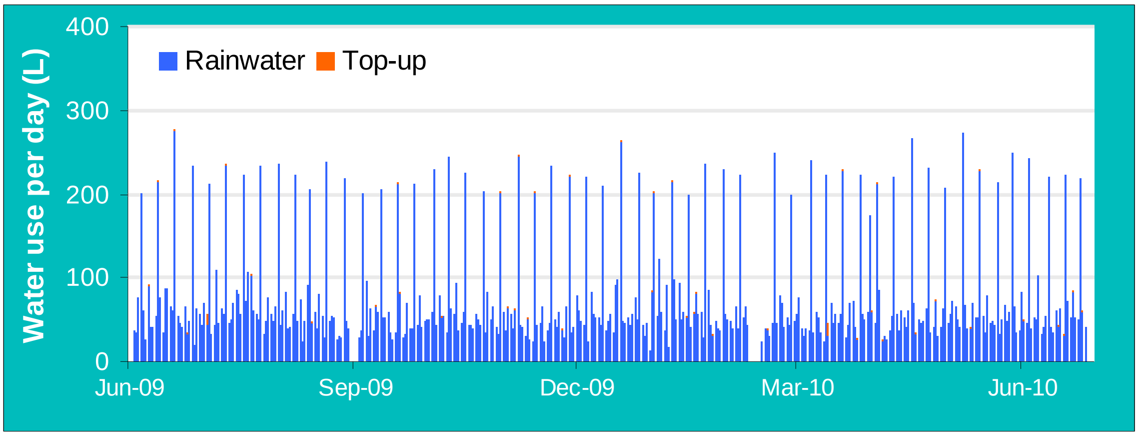

Figure 10: Daily rainwater use profile for a household showing toilet and washing machine use

However, Figure 11 shows that a seasonal demand exists for this household for its potable mains demand. This seasonal demand appears to be consistent with an outdoor demand as during summer months the fortnightly rolling average demand increased from around 200 L/day to about 700 L/day.

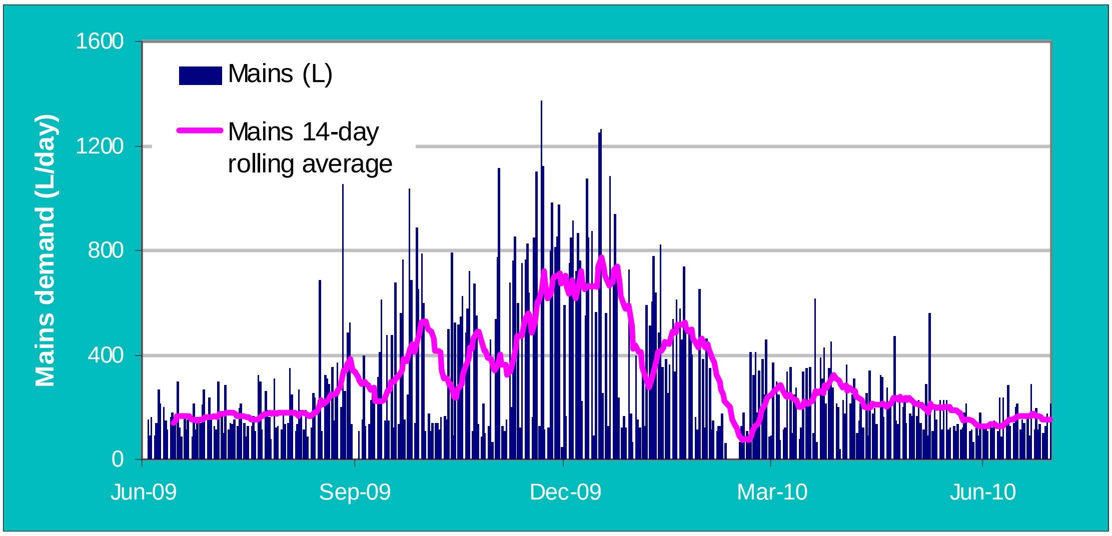

Figure 11: Daily mains demand for a household showing summer seasonality

If this household connected this outdoor seasonal mains demand to the rainwater tank, modelling shows that rainwater tank water savings could increase from the actual savings of 27,300 L/year to more than 45,000 L/year. This uses the significant spare capacity available in the tank due to the low demand from connected uses.

3.3.5 Seasonal demands

Indoor water use for washing machine use and toilet use is fairly regular throughout the year. In contrast outdoor demand can fluctuate significantly throughout the year, being typically high in the summer season and low in the winter season. This is referred to as seasonality.

Figure 12 summarises the average water demands by month for all households. It shows the cumulative use of rainwater, potable top-up for rainwater tank connected uses and other potable mains demand for the household.

Key points to notice:

- There appears to be seasonal demand between November 2009 and January 2010 for both rainwater-connected uses and non-rainwater tank connected uses. This is consistent with the findings above that not all households are fully connecting outdoor uses to their tanks.
- The higher demand periods August to September 2009 and November to December 2009 are consistent with dry periods during the assessment period (refer Figure 8). This is reflected in the increased potable top-up at these times.

As can be seen, short-term monitoring studies that monitor shorter periods may under or over estimate total water savings, depending on which season the monitoring occurs. As this study targeted a continuous 12 months monitoring period the impact of seasonality should not significantly affect the results, although seasonality is likely to vary marginally year to year depending on weather conditions.

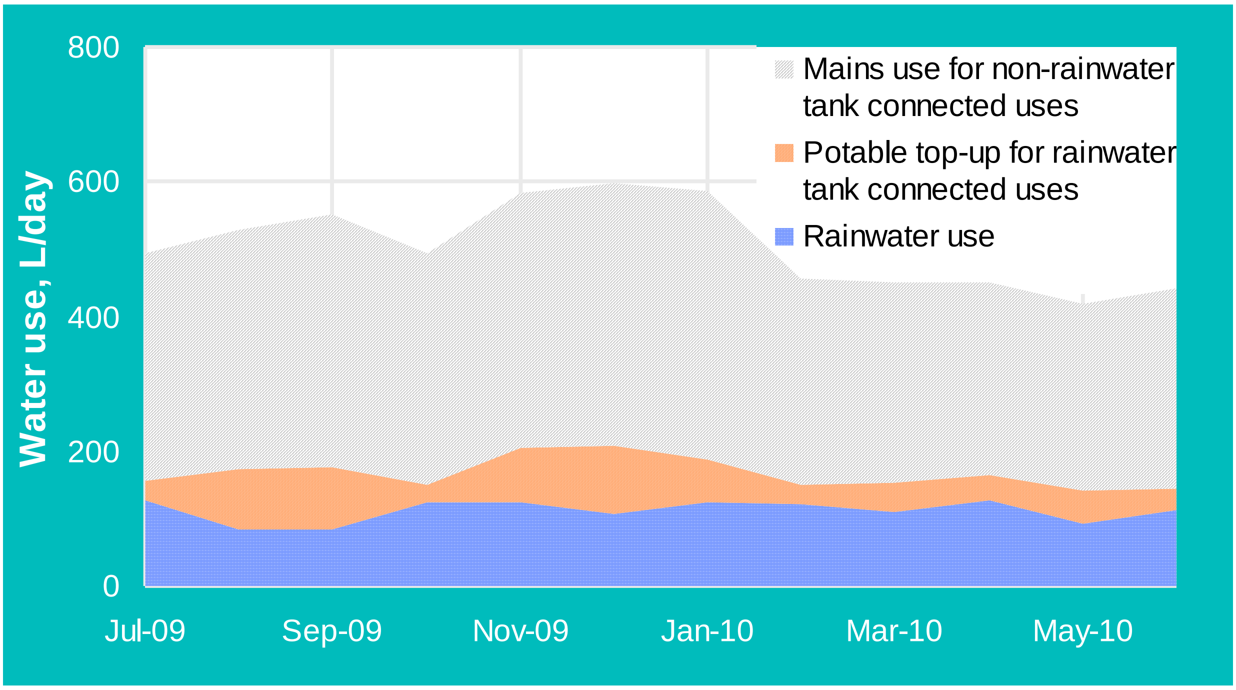

Figure 12: Average monthly use of rainwater, potable top-up for rainwater-connected demands and mains potable for non-rainwater tank demands for all households

3.3.6 Regional differences in water savings

There have been many discussions throughout the industry on the effectiveness of rainwater tanks located in inland drier environments compared with coastal locations with higher rainfall.

To investigate the effect of different rainfall on rainwater tanks in this study, households were classified as being either coastal (eastern Sydney) and or inland (western Sydney) – refer Figure 1 for how the households were allocated. Sydney has high average rainfall in coastal areas (see Section 3.3.1)

Key results comparing coastal and inland performance are shown the table below:

	Coastal	Inland
Sample size	20	19
Water savings, rainwater use in kL per year	43	36
Rainwater tank connect demanded, kL per year	68	52
Reliability, % of rainwater tank connected demand met by rainwater	63%	69%

The table above shows that coastal-based tanks in the study saved more water than inland-based tanks but this was primarily due to a high demand for rainwater.

The results of this study indicate that the difference between the reliability of coastal versus inland tanks for this study is minimal. The reason for this is that, for equivalent households, the calculations in the BASIX tool take into account local climatic conditions such as rainfall, temperature and evaporation. As such, it requires for larger tanks for lower rainfall inland households, for the sample an average of 3,600 L for coastal tanks and 4,300 L for inland tanks. It also require larger roof area connections for inland households, for the sample an of average 180 m^2 in the east and 260 m^2 in the west. These requirements increase the reliability of inland tanks for lower rainfall.

4 Results: Linking water use to energy use

Pumping energy use is affected by the how often a tank pumps to different end uses and the flow rate at which water is pumped. The following sections use the monitoring data to identify how often different sized water use events occur, which relates to end use, and at what flow they occur, which relates to flow rate.

In later sections 5.3.3 and 5.3.4, the effects of water use events and flow on energy use are discussed.

4.1 Water use events

4.1.1 Definition of a water use event

End uses cannot be easily determined from monitoring data for a complete data set. This is due to the variation in end use profiles and the impact of overlapping events. The use of water use events has been found to be a more effective method for analysing the impact of water use on pump energy use.

For the purpose of the analysis, a water use event is a use of water within one or more minutes that is surrounded by no water use. The water use includes any demand from a rainwater-connected end use regardless of its supply (rainwater or potable water through top-up). Water use events vary from a half-flush toilet event of 3L within a minute period to an irrigation or other outdoor event of 1000's of litres over a long period of time. A water use event may include overlapping events (ie simultaneous toilet and irrigation use).

Figure 13 shows an example of the metered one-minute data results for rainwater-connected demands. It can be seen that there are five discrete water use events. Three events occurred within the one-minute monitoring period. One water use event happened over two minutes and the other major water use event occurred over a 9-minute monitoring period.

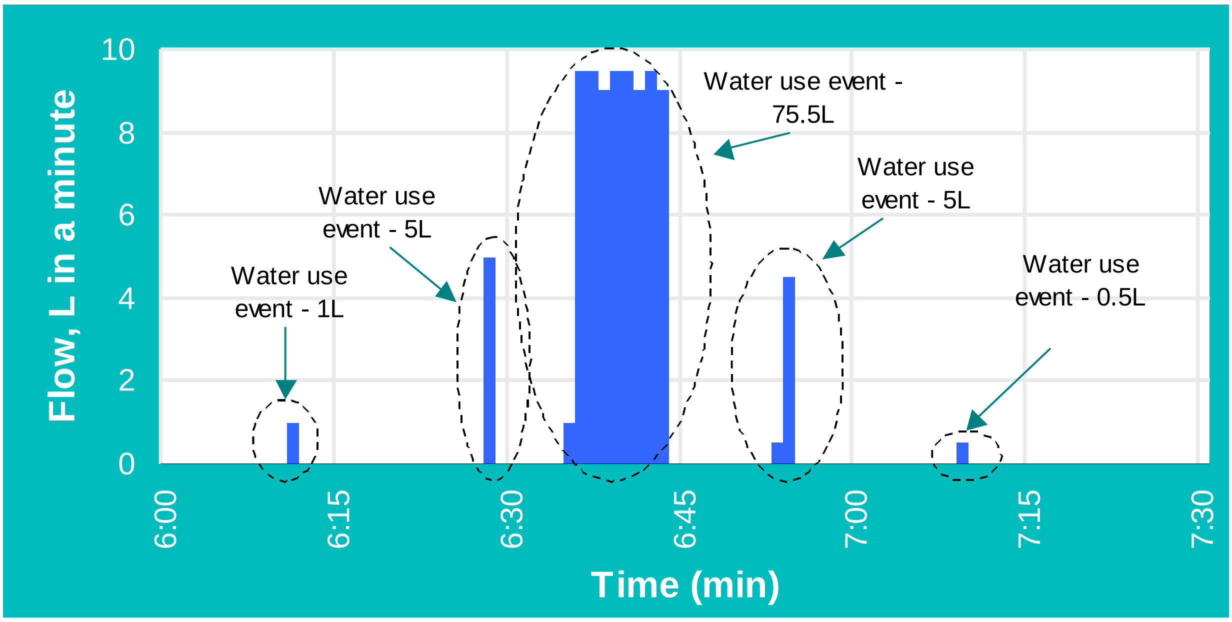

Figure 13: Example of monitoring outputs showing continuous water use for five discrete water use events

4.1.2 Incidence of water use events

Figure 14 summarises the contribution of different size water events to total demand from rainwater tank systems. Key points of interest are:

- Events of between 4.5L and 9L made up the largest proportion of demand, accounting for nearly 30% of total demand. This is likely to be made up mostly of full flush toilet events.
- Events of over 100L (most likely irrigation and some washing machine demands) made up less than 20% of total demand.
- Measurable leaks (0.5 to 2 L for events that are above the resolution of the water meter) made up a very small proportion of total demand from the tanks.

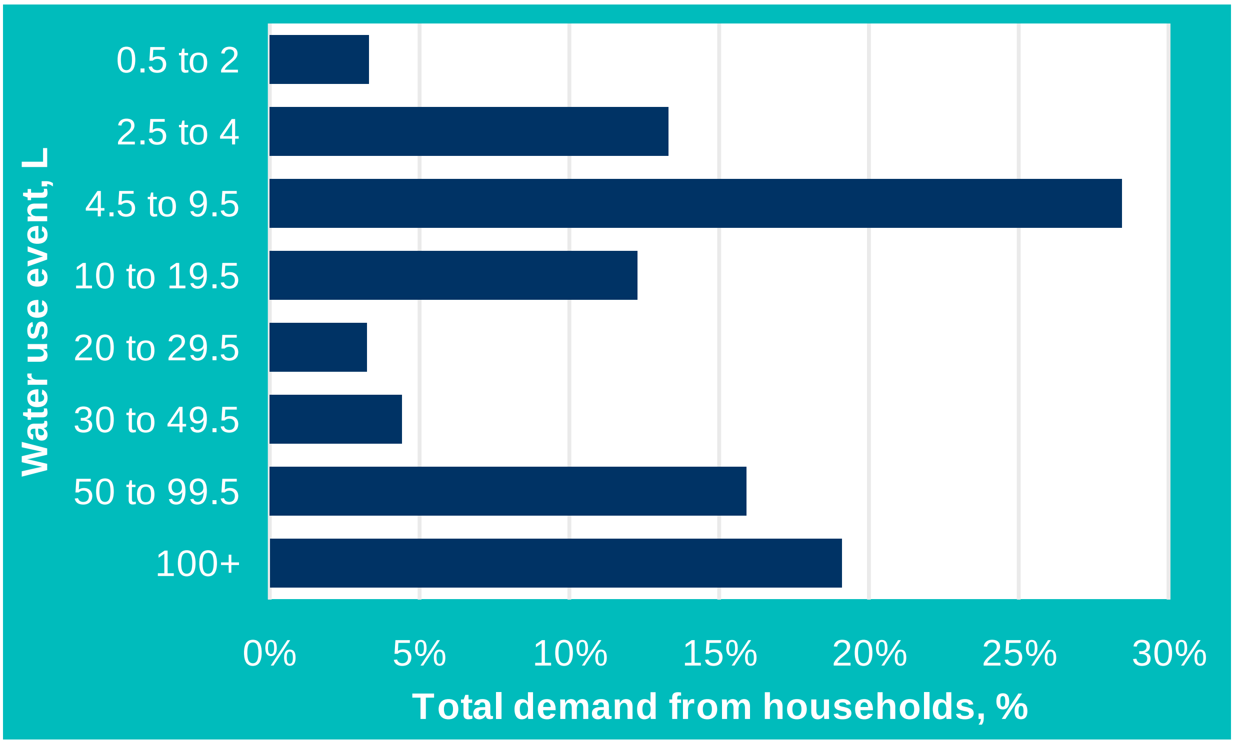

Figure 14: Incidences of water use events for all households

4.2 Flow

4.2.1 Definition of flow

Flow in this study refers to the amount of water used from the tank within a one-minute interval data collection period, ie L in a minute. At high flow rates (ie L per minute) it is likely that will correlate with flow (ie L in a minute). At lower flow rates they will likely not correlate with flow.

That is because a toilet fill event, of say 5L, will start and stop well within a one-minute period. This means the flow rate may be higher than flow recorded within a one-minute period.

Flow rates (ie L per minute) cannot be directly determined from one-minute interval data and would require much smaller time steps. The limitation of collecting smaller time steps is the impact on the ability to collect the data continuously using remote monitoring.

4.2.2 Flow occurrence

Pumps operate at different levels of efficiency depending on flow rates. At low flow rates, pumps have been found to operate less efficiently and therefore have increased energy intensity. This is why it is critical to understand how often different flow rates occur, especially low flow rates, so that pumps can be sized optimally to meet these flow rates.

Figure 15 shows the distribution of flow events for the monitored households over the analysis period. It shows that the majority of flows were less than 5 L in a minute. This is consistent with the majority of water use events (see section 4.1) being toilet flush events or leaks between 1 L and around 8 L, where a flush event is spread over two separate minute interval periods.

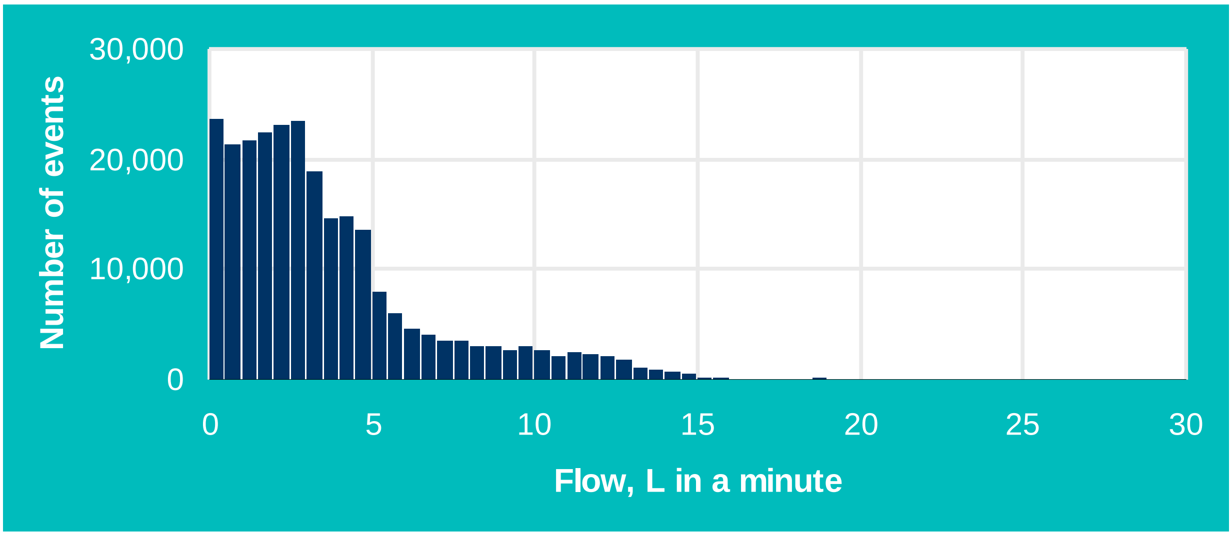

Figure 15 Distribution of events by flow in a minute for households

While toilet flushing and leaks dominate the number of events of different flow rates, more important for energy efficiency is how much volume occurs at different flows. Figure 16 shows the cumulative percentage of rainwater tank connected water use, by volume.

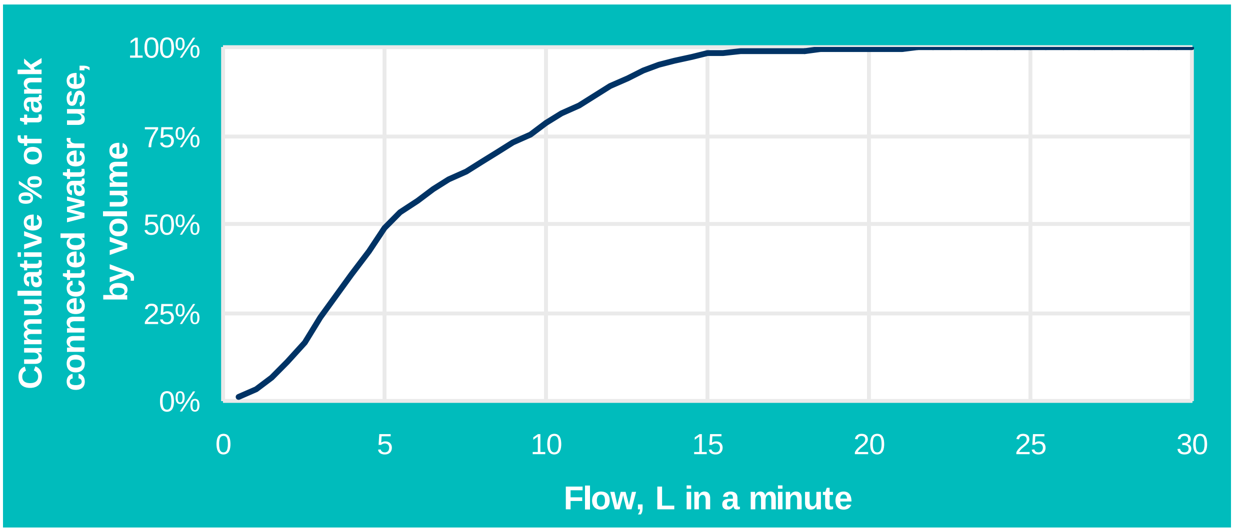

Figure 16: Cumulative percentage of rainwater tank connected water use, by volume, for all households

Less than 2% of the volume occurs at more than 15 L in a minute, despite larger pumps being designed to cater to these flow rates.

Almost 50% of the volume used by rainwater-connected uses is for flows of 5 L in a minute or less. This is despite flows of 5 L in a minute or less accounting for approximately 75% of the flow events.

The remaining 50% of volume occurs between 5 L in a minute and 15 L in a minute. Flow in this region is dominated by demand for washing machines, irrigation and other large use events. Analysis of washing machine demand shows that most washing machines were operating at around 10 to 12 L per minute while filling. Irrigation events were found typically to be between 10 L per minute and 15 L per minute.

These results show that pumps that operate efficiently at low to moderate flow rates are critical for ensuring rainwater tank pumps operate efficiently, especially for those tanks that are only connected to non-potable demands such as toilets and washing machines.

4.2.3 Maximum rate of flow

Maximum flow in a minute was identified for each household. For higher flows, flow is likely to be equal to flow rate. For low flows, this may not be true. The results are shown below.

	n	Median	Mean	Minimum	Maximum
Highest achieved flow, L in a minute	42	16.5	15.5	4.5	28.5

Of interest is that the median flow (rate) is similar to that of a typical reticulated network of 15 to 20 L/min.

5 Results: Energy use

5.1 Pump energy for rainwater tank connected uses

Household energy use for rainwater tank pumps was:

	n	Median	Mean	Minimum	Maximum
Energy use, kWh/year	42	62	78	7	336

At a typical energy cost of 20c/kWh, this equates to an average of $15 a year or maximum of $67 a year for operating the pump.

5.2 Energy intensity for water saved by rainwater use

Total energy intensity was:

	n	Median	Mean	Minimum	Maximum
Total energy intensity, kWh/kL	41	1.48	2.08	0.76	10.8

The results have shown that there is a wide variability in energy intensity performance amongst households. The majority of household pumps are operating between 1 to 2 kWh per kL, with the majority of the remaining pumps operating between 2 to 3 kWh per kL. Only two households had energy intensity above 4 kWh per kL, with the maximum energy intensity being 10.8 kWh per kL. An explanation for this household's high energy intensity is discussed in Section 5.4.

The variability of energy intensity is shown in Figure 17, where total energy intensity is plotted as water savings versus energy use for each household. Energy intensity gradients are also shown.

In general, above ground pumps were found to perform better than submersible pumps for energy intensity. For that reason, submersible pumps are shown in red and above ground pumps in blue on the figure.

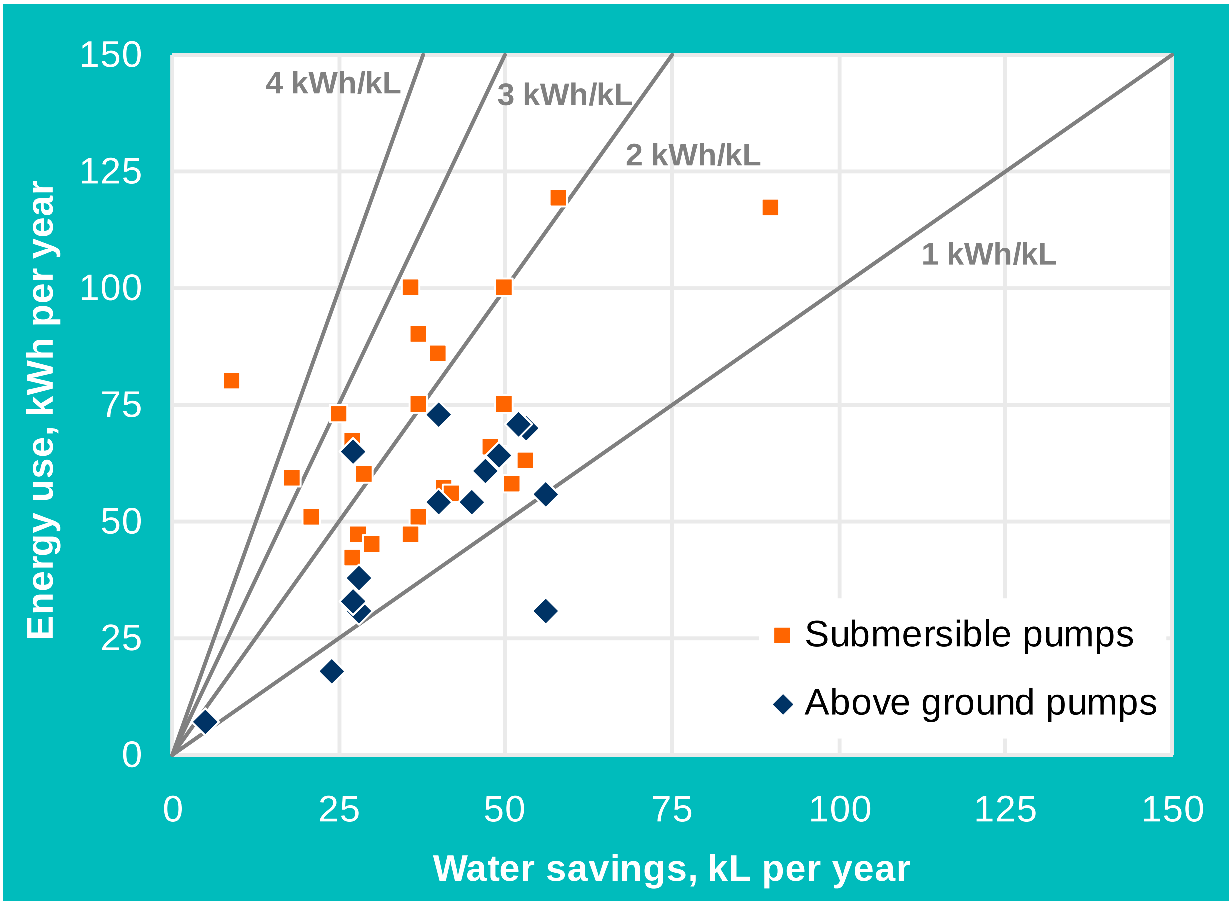

Figure 17: Comparison of energy use (kWh per year) versus water savings (kL per year) for each household, excluding two largest energy users

Not shown on the graph (so the graph has better resolution) are two households that used more than 150 kWh per year.

- Household 1 had a total energy demand of 227 kWh per year for a rainwater tank demand of 58 kL per year, which equates to an energy intensity of 3.94 kWh per kL.
- Household 2 had a total energy demand of 336 kWh per year for a rainwater tank demand of 53 kL per year, which equates to an energy intensity of 6.38 kWh per kL.

Pumps use energy both to actively pump water and on standby. Total energy intensity (kWh per kL) does not provide any information on active pumping performance nor standby energy use with water volume dominating the outcome. For that reason, total energy intensity can be misleading.

One-minute intervals allow for a direct comparison of active pumping, including during different size water pumping events and standby energy use. This provides better guidance on the relative performance of rainwater tank pumps than total energy intensity (which is highly driven by the sample of households selected and the period of analysis). Due to the variability in demand and use profiles of households, total energy intensity studies are unlikely to be representative with small sample numbers. This partially explains the variety of energy intensity values in literature.

Figure 18 is a sample monitoring period that shows the difference between active pumping and stand-by energy use.

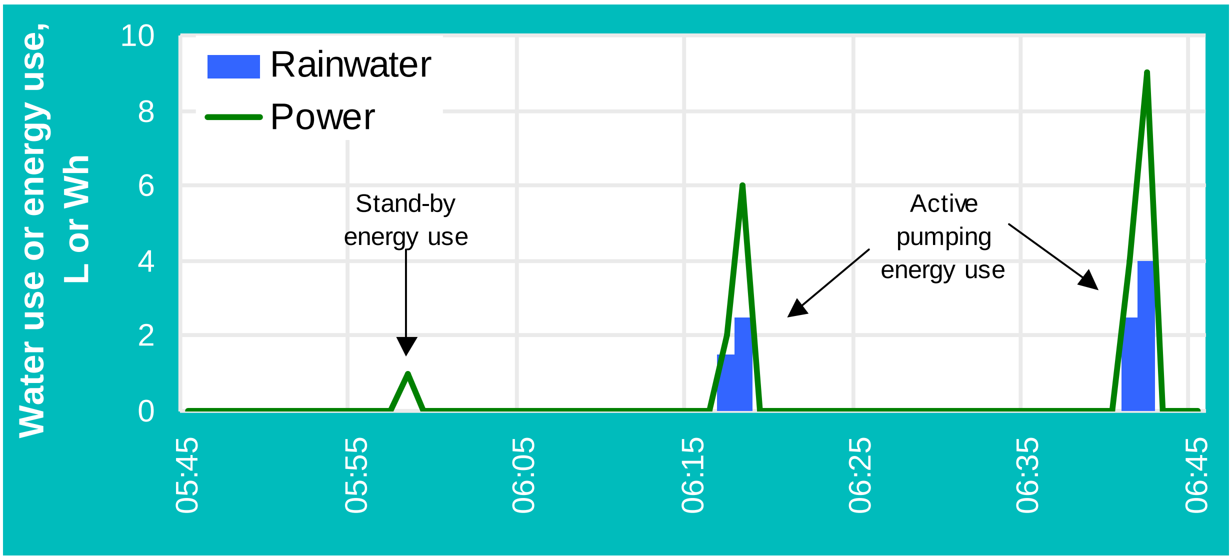

Figure 18: Example of the monitoring data output showing the difference between stand-by use and active pumping demand energy use

5.3 Discussion of identified factors that influence total energy use

Energy intensity is highly variable due to the number of factors that influence energy use of rainwater tank pumps. These factors include:

- Stand-by energy demand (dormant)
- Active pumping energy demand
- End uses and connections
- Pump sizing (capacity) and relationship with flow rates
- The types of water use events
- Changes in demand patterns over time
- Pressure tanks
- Seasonal fluctuations in demand.

These factors are now discussed in the following sections.

5.3.1 Dormant (or stand-by) energy use for the pump

Rainwater pumps have been found to have low dormant energy use with the exception of a few properties that significantly increase the average. Dormant use for the purposes of this study includes any measurement of energy use (1 or more Wh) during a one-minute interval (resolution of 1 W rms or better) that is not matched with a measurement of water use. Dormant use may include stand-by energy for the pump when it is in idle or water use events that are below the water meter threshold but trigger a pump event.

The energy demand for dormant uses was

	n	Median	Mean	Minimum	Maximum
Dormant energy use Wh/day	41	7	29	1	630

The pumps consumed on average 29 Wh/day or 11 kWh/year (~$2 per year). This is an insignificant energy demand, even including the single property with significant stand-by demand as shown in the case study below.

High dormant use is likely to be from leaks occurring in the system that are identified by the water meter (low flow leaks) but are triggering a pumping event.

There are a number of possible solutions to this problem, including:

- Introduction of pressure tanks that decrease pump start frequency by increasing the change in volume required before pumping.
- Introduction of alarms with pump systems that operate continuously.

Case study: The impact of stand-by energy use as shown for an outlier property

A single outlier household had a significantly higher dormant use than the remaining households. For this household, standby energy is a significant part of total demand. This household's demand profile is shown in Figure 19.

For this property, it can be seen that energy use varies in response to rainwater use. It can also be seen that during periods of top-up only, such as during the end of August, pumping energy is much greater than zero indicating that there is a significant stand-by energy use (around 630 Wh/day). Unlike other households that were found to fix issues such as these, this household is obviously unaware or is choosing not to fix the problem.

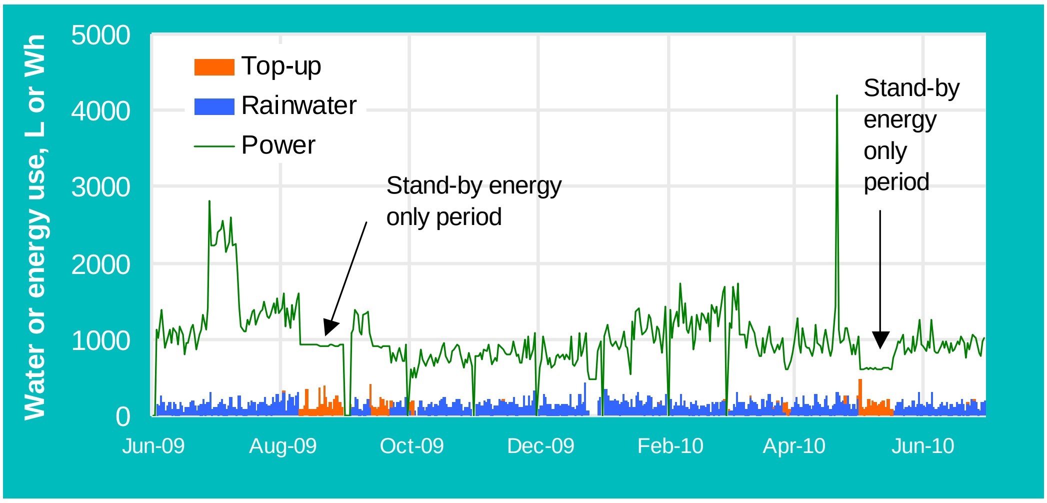

Figure 19: Household with high dormant energy use for the entire monitoring period– daily data – update graph with new format and highlight period with stand-by use

Investigating stand-by energy use in more detail, Figure 20 shows the energy profile for this household's pump during an operational period (data is in 1 minute intervals). As can be seen, energy use is occurring where no water use event is occurring, with the energy meter recording a 1 Wh energy pulse roughly every 5 minutes. Between 5.58 and 5.59 am, a toilet flush event occurs (between 6.5 and 7.5L has occurred) leading to increased pump energy at that time. Stand-by energy use then continues after this period.

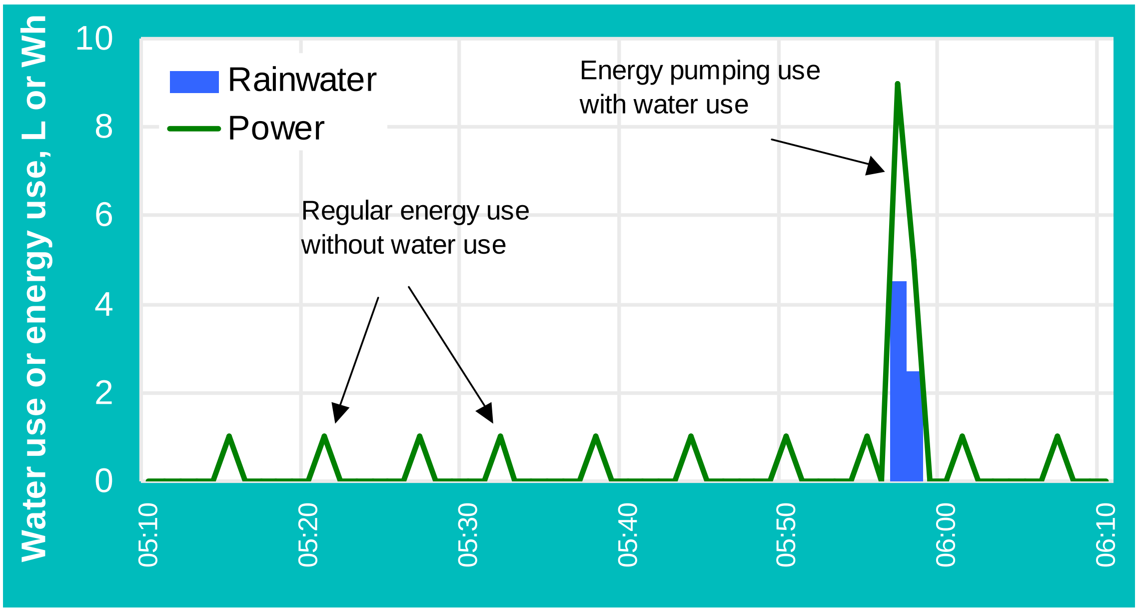

Figure 20: Household with high dormant energy use for the entire monitoring period – one minute interval data for a selected period

5.3.2 Active energy intensity (pumping energy demand)

To evaluate the efficiency of active pumping for a given household, energy use was identified during each water use event for each household. Energy use that directly correlates with a water pumping event is assumed to be due to active pumping energy demand.

The resulting active energy intensity results for each household with suitable data was:

	n	Median	Mean	Minimum	Maximum
Active energy intensity, kWh/kL	41	1.42	1.83	0.63	9.42

As can be seen, the median active energy intensity has reduced slightly from the median total energy intensity (1.48 kWh/kL as in Section 5.2). Factors that contribute to active pumping energy intensity are discussed in the following sections.

5.3.3 End use energy intensity

By classifying water use events, it is possible to build a profile of energy use intensity for different end uses.

For each household a water use incidence diagram was developed to assess likely volumes for half flush, full flush, washing machines and large use events (irrigation, pool filling etc) for each household. An example of this for a single property is shown in Figure 21. High incidence or clustering of water use events at a certain volume indicates the likely presence of a single end use. Not all households were identifiable for all end uses. Where clustering is not present, water events are likely due to mixed events.

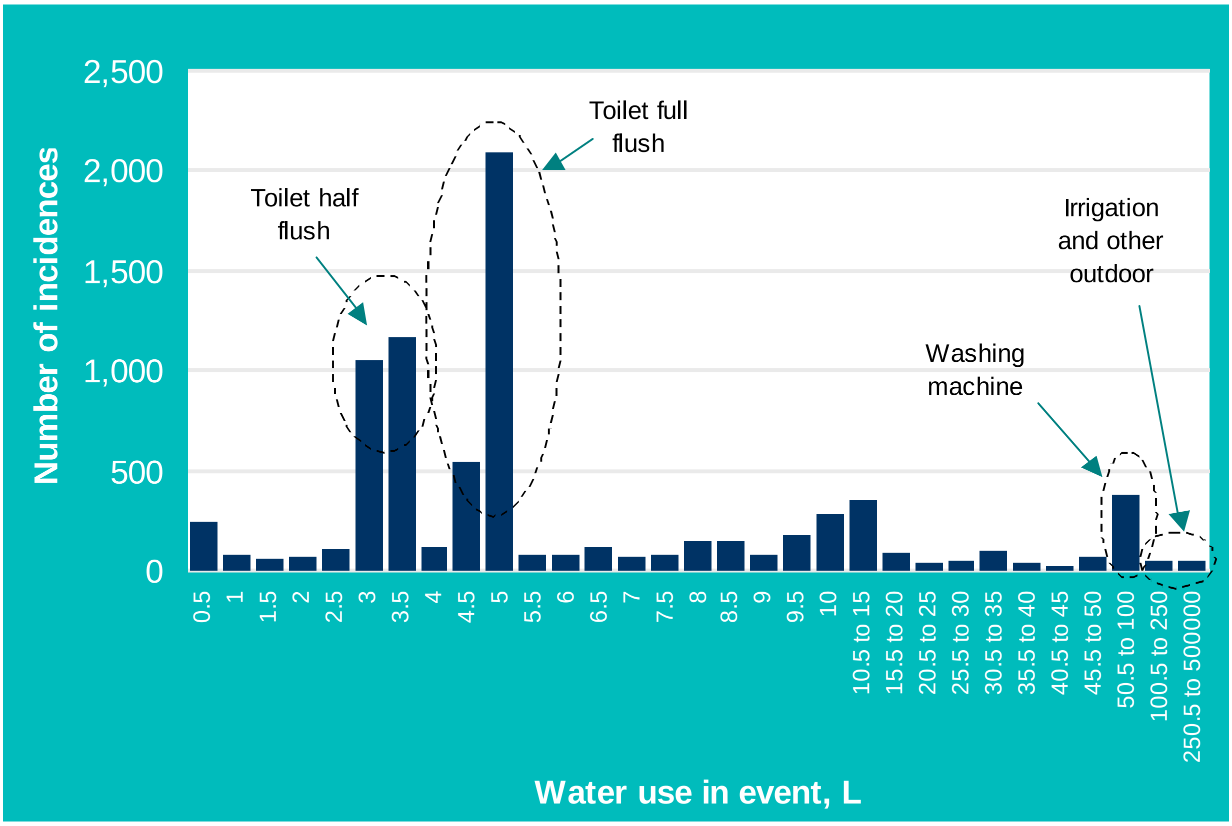

Figure 21: Example identification of end uses by using water event incidences for a household

The resulting active energy intensities (kWh/kL) calculated across all households were:

	n	Median	Mean	Minimum	Maximum
Toilets – half flush	34	2.08	2.48	1.22	13.24
Toilets – full flush	34	1.84	2.12	1.15	8.83
Washing machines	18	1.29	1.72	0.88	7.00
Large use events	34	1.20	1.24	0.36	2.80

Across all households these results show that there is a clear improvement in energy intensity trends as water use event volume increases. Toilet use has the highest energy intensity, followed by washing machines. Large use events[2] have the lowest energy intensity. Toilet uses were generally more energy intensive because they typically fill at a slower rate than washing machine and irrigation uses.

[2] Large events were typically irrigation events but may also include other outdoor uses such as the filling of pools.

For well performing pumps (where their energy intensity was below the median), the results begin to converge as follows

	n	Median	Mean	Minimum	Maximum
Toilets – half flush	17	1.56	1.64	1.22	2.47
Toilets – full flush	17	1.48	1.50	1.15	2.10
Washing machines	12	1.22	1.17	0.88	1.47
Large use events	18	0.96	0.97	0.36	1.58

This results show that for well performing pumps, the difference in energy intensity between toilet events and washing machine events are usually less significant.

5.3.4 Correctly sizing pumps

Pump selection, particular for sizing, is critical to the energy efficiency of a rainwater tank pump system. Pumps need to be sized to balance with required pressure for use and the energy efficiency of the pumps. If pumps are over-sized, pumping is less energy efficient at the expected flow rate. If pumps are under-sized, pumping is more efficient but will not meet required flow rates.

For the study, pump size was not able to be determined for all submersible pumps and for some above ground pumps due to limited access or specification data being available. Pump energy intensity curves were developed from the data to estimate pump sizing and performance.

5.3.4.1 Pump energy intensity curves

To better understand the variability of the active energy intensity, pump energy intensity curves were developed. Pump energy intensity curves can show the energy intensity of pumping at changing flow rates.

Figure 22 shows the average pump energy intensity curve for submersible and above ground pumps. The pumps were assessed separately due to their difference performance for energy intensity.

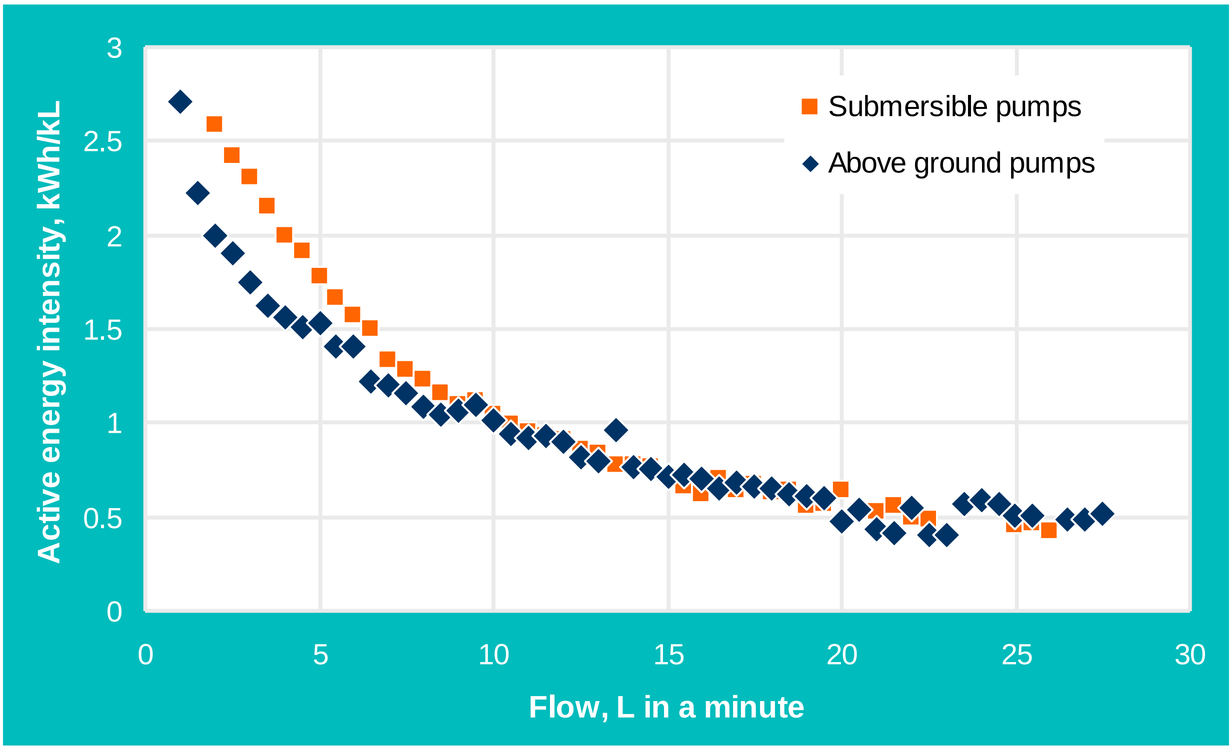

Figure 22 : Average pump energy intensity curve split by pump type (excluding very low flow events)

The graph shows that:

- as flow increases, there is a decreasing energy use rate per L. This is consistent with expected outcomes from pump specifications.
- at higher flows, submersible and above ground pumps operate at very similar active energy intensity.
- at low flows (less than 10 L in a minute), the average energy intensity for submersible pumps diverges from above ground pumps.

This explains why submersible pumps in the study have higher energy intensity than above ground pumps, as due to end uses, more pumping events occur at low flow rates and small volumes (see section 4.1).

Case study 1: Pump curve for a single household comparing monitored data with specifications and a discussion of the difference between flow and flow rate

The difference between flow and rate can be better understood by looking at the results for a single household with known pump specifications – above ground 770W pump that is assumed to be operating at 65% efficiency (refer **Figure 23**).

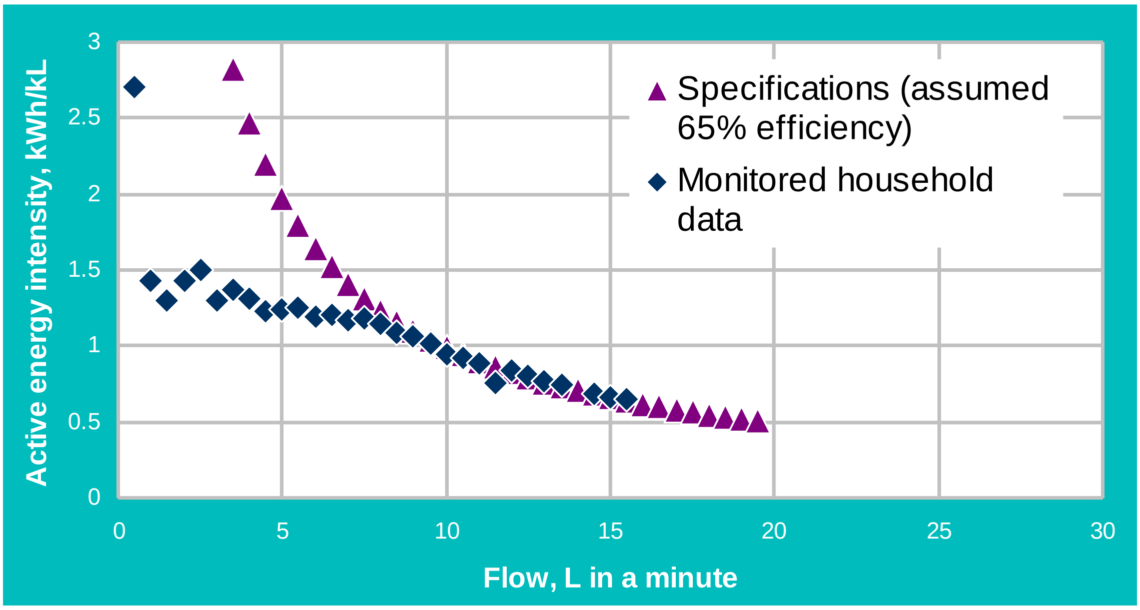

Figure 23: Comparison against specifications for a pump at a single household

As can be seen, at high flow rates, the pump is operating close specifications, assuming the pump is operating at 65% efficiency. Above 8 L in a minute, flow (L in a minute) is likely to be the same as flow rate (L per minute).

At low flows, less than 8 L in a minute, flow is less likely to correspond with flow rates, as events are more likely to last less than a minute. For example, a flow of 5 L in a minute may occur at a rate 10 L per minute lasting for 30 seconds.

Case study 2 : A comparison of three significantly different household pump curves

Figure 24 shows for three households the impact of pump selection on energy intensity by showing their pump curves.

Household 1 has an efficient pump as shown by the small variation in energy intensity regardless of flow. This is partly because this household's demand is dominated by large use events and has a small pressure tank (see section 5.3.6).

Household 3 has a pump curve close to the average for the sample. It shows increase energy intensity at low flow rates.

Household 2 has a submersible pump which is oversized. This pump has been designed for higher flows than it receives meaning that it pumps at very high energy intensity at low flow rates typically found with rainwater tank demand.

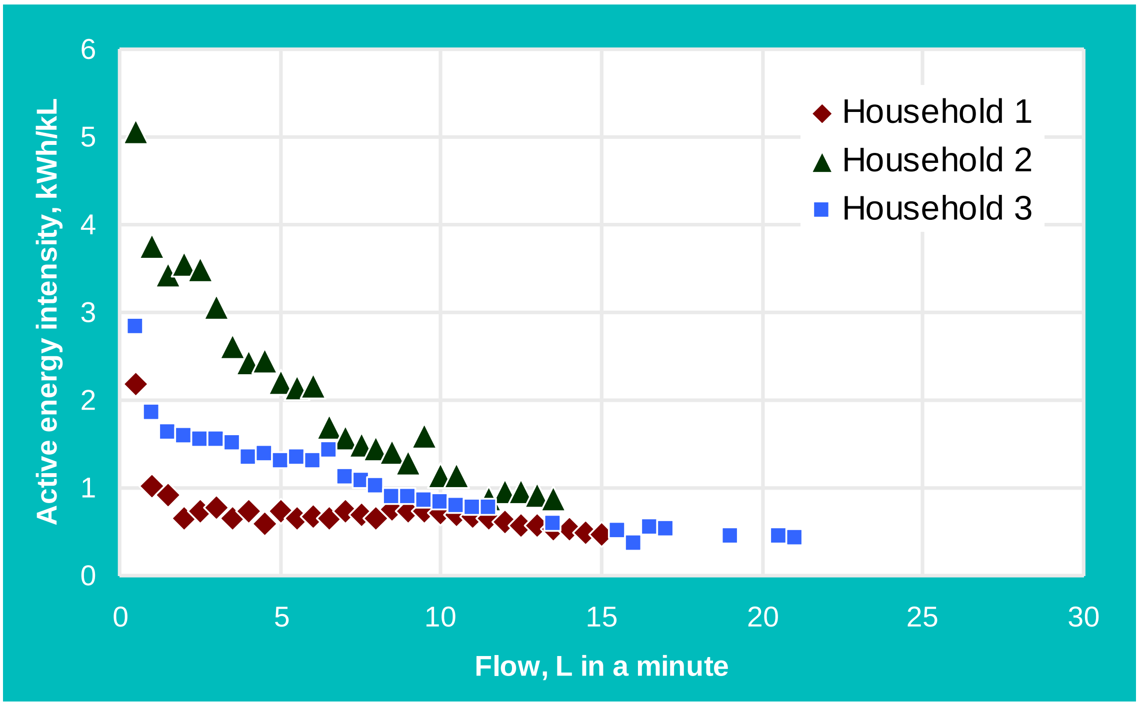

Figure 24: Examples of different pump curves for three households

These curves in the above case study indicate that achieving efficient pump selection depends on

- the maximum flow rate that is required
- the proportion of demand that is low flow events?

These are now discussed further.

5.3.4.2 Designing pumps for maximum flow and flow rates

When selecting a pump, it is important to select a pump that will achieve the maximum flow rate required by your end uses. If a high flow rate is required, this will require a larger pump that may be less energy efficient at lower flow rates. The following is an assessment of maximum flow rate achieved for the households and therefore will provide guidance on design of pumps for urban residential use of rainwater tanks.

On an individual household basis, Figure 25 compares the maximum flow achieved for each household with their active energy intensity to identify any trends.

It can be observed that:

1. As maximum flow rate increases, pumping becomes more efficient.
2. The maximum flow rate for each household, with a sample median of around 15 – 17 L per minute, there is a wide spread of achieved average energy intensities, from around 0.6 kWh/kL to 2.5 kWh/kL.
3. There is no significant difference in maximum achieved flow rate between submersible and non-submersible pumps. This shows that despite submersible pumps being notionally larger and

therefore less efficient, they are not achieving higher maximum flow rates. This is because they are end use restricted by flow rate.

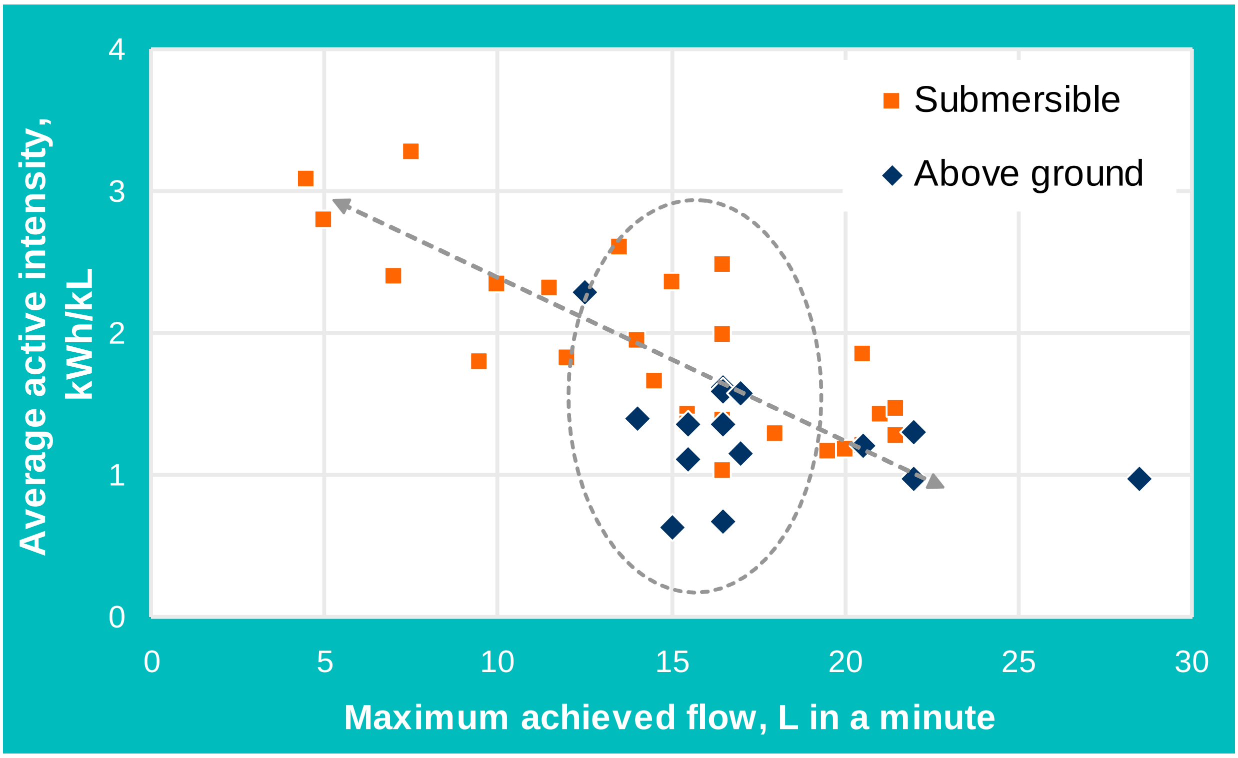

Figure 25: Comparison of average active intensity vs maximum achieved flow rate by household (excluding outlier of 9.42 kWh/kL at a maximum flow rate of 13 L in a minute)

Figure 26 further investigates this trend, by comparing the minimum active intensity achieved by each household with its maximum achieved flow rate. We see that the data reverts to a curve similar to a pump curve. That is, the difference in minimum achieved energy intensity is directly related to the flow rate and not significantly impacted by pump type at high flow rates. This is consistent with the pump curves shown in Figure 22.

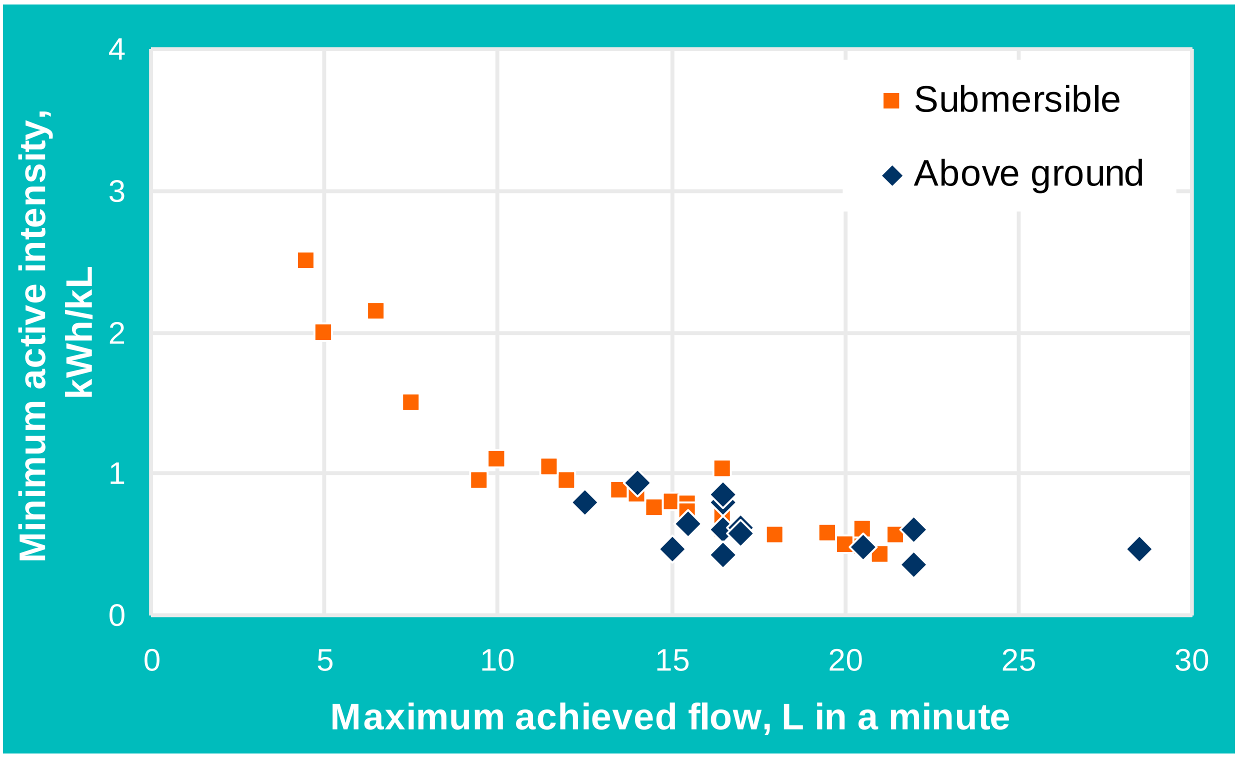

Figure 26: Comparison of minimum active intensity by maximum achieved flow rate

5.3.4.3 Relationship between pump energy intensity curve and monitored median energy intensity

By revisiting the pump energy intensity curve developed in section 5.3.4.1 and the flow rates identified in section 4.2.2, it is possible that we could estimate the active energy intensity of the households.

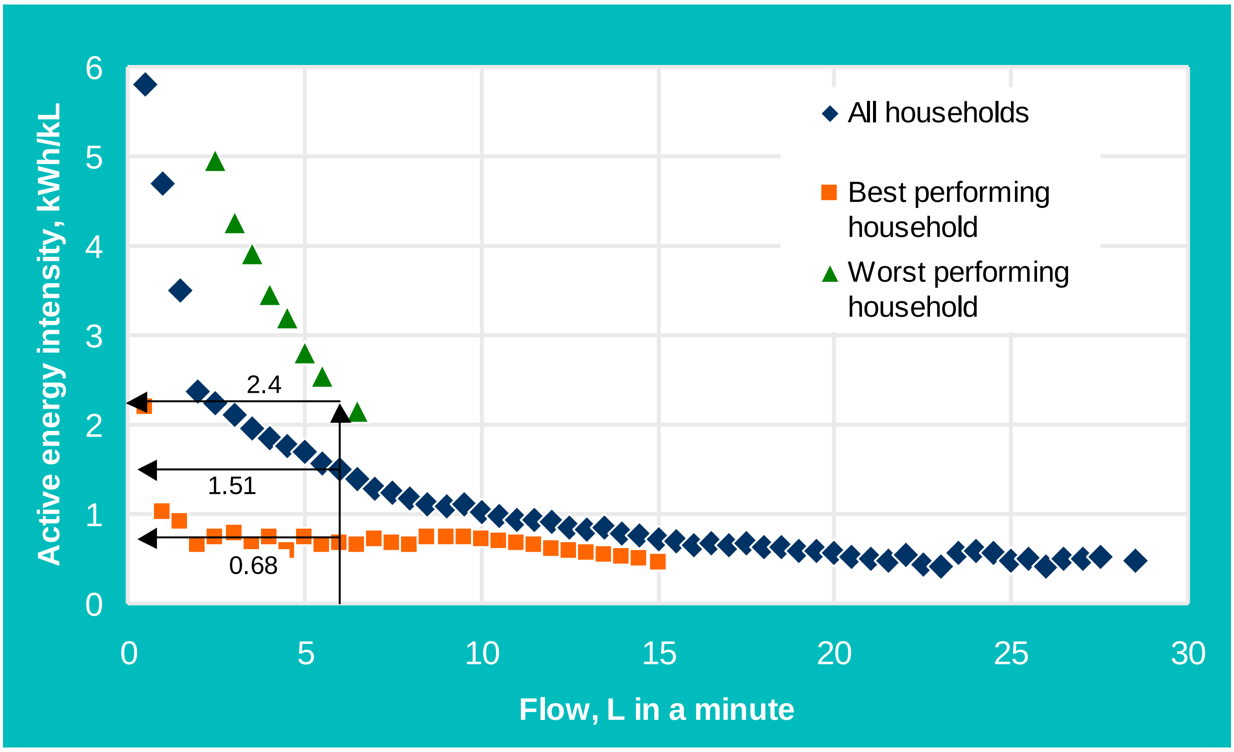

Figure 27: A comparison of pump energy intensity curves for all households and the best and worst performing households at 50% flows

For all households, with median flows of 6 L in a minute and the average household pump energy intensity curve, the estimate for all households for the median active pumping energy intensity is 1.51 kWh/kL. This compares favourably with the actual average median active pumping energy intensity of 1.42 kWh/kL.

Pump selection within the selected households show that this average could be as low as 0.68 kWh/kL if all households had the most efficient pump to 2.4 kWh/kL for the least efficient pump.

This graphs illustrates the importance of appropriate pump selection for rainwater tanks. As many households have been found to predominantly use their tanks for toilets and some washing machine uses, rather than high flow rate irrigiation events, this highlights the importance of choosing a pump that operates efficiently at low flow rates.

This may include the use of a pressure tank that reduces low flow rate events. For further discussion of this see Section 5.3.6.

5.3.5 Trends in energy intensity

Energy intensity can change significantly over time. This may be due to changing user patterns, leaks (periodic or systemic) and/or changes in pump performance.

Of the households able to be assessed for trends, 27 households had a relatively stable energy intensity trend. The case study below shows stable trends for three households.

Case study: Three households with stable but different energy intensity trends

Figure 28 shows three households that had stable energy intensity trends.

Household 1 only used rainwater for toilets each day, so the energy intensity remained almost constant over the period.

Households 2 and 3 show a stable trend with energy intensity varying day to day, with energy intensity depending if the uses during the day were toilet flushing only (higher energy intensity) or were a combination of washing machine use and toilet use (lower energy intensity days). Household 2 has more frequent washing machine use days than household 3 as can be seen by the increased number of lower energy intensity days.

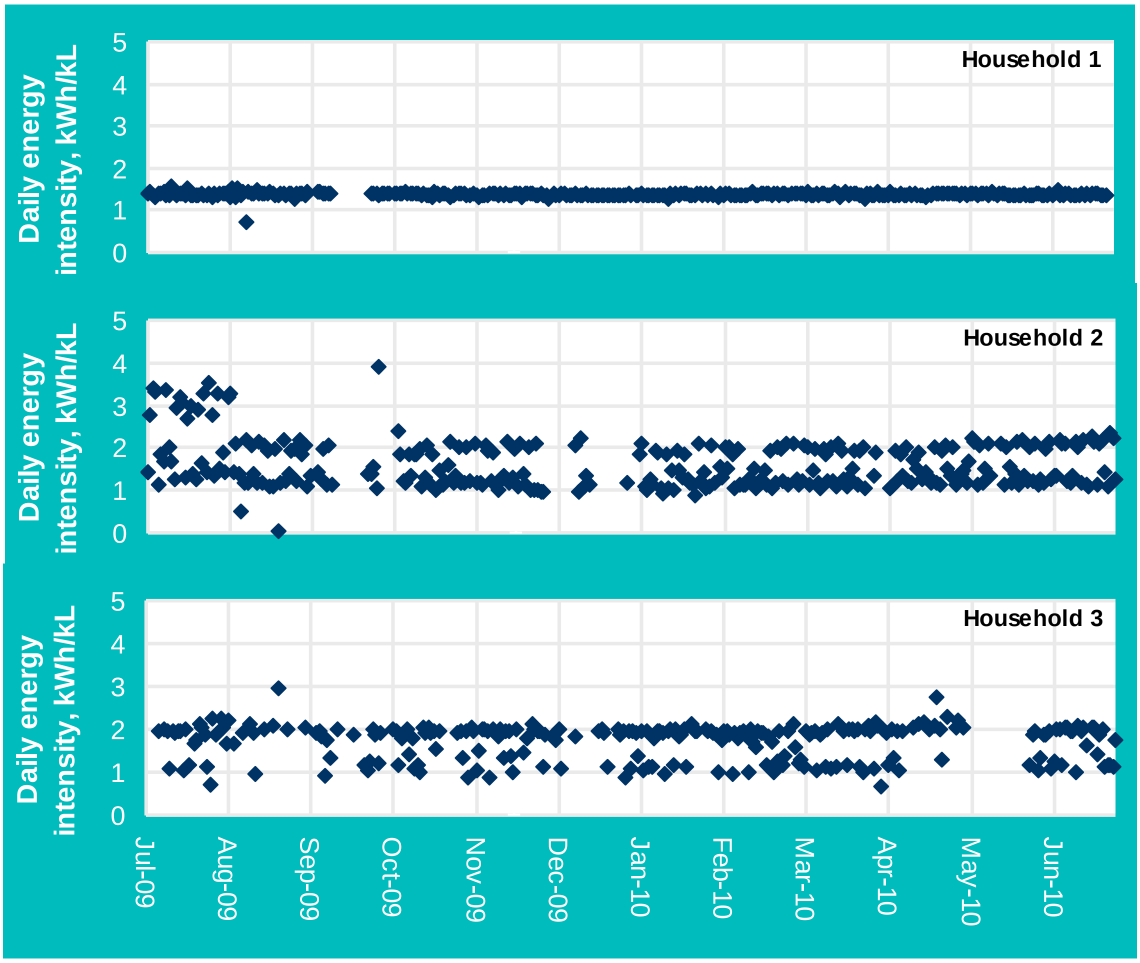

Figure 28: Energy intensity trends for properties showing relatively stable trends

Sixteen households were identified to have unstable energy trends over the period. These changes in trends could be growth, decays or fluctuations in energy intensity. These may be due to significantly different demand patterns or leaks within the system. The case study below shows unstable trends for three households.

Changes in trends on an individual household basis highlight the importance of achieving realistic estimates of energy intensity by long term monitoring when using small samples.

Case study: Three households with unstable but different energy intensity trends

Figure 29 shows three households with unstable trends, where changes may occur quickly (major leak or major change in demand pattern) and slowly (growth in leak or seasonal changes in demand).

Household 1 shows a household that had a significant growth in energy intensity between October and December and then stabilised back to normal levels after February.

Household 2 shows an average growth in energy intensity over time that has not been corrected by the household. This may be due to a leaking toilet that has not been fixed by the household.

Household 3 shows a household where there was a step reduction in energy intensity, possible due to a repaired leak.

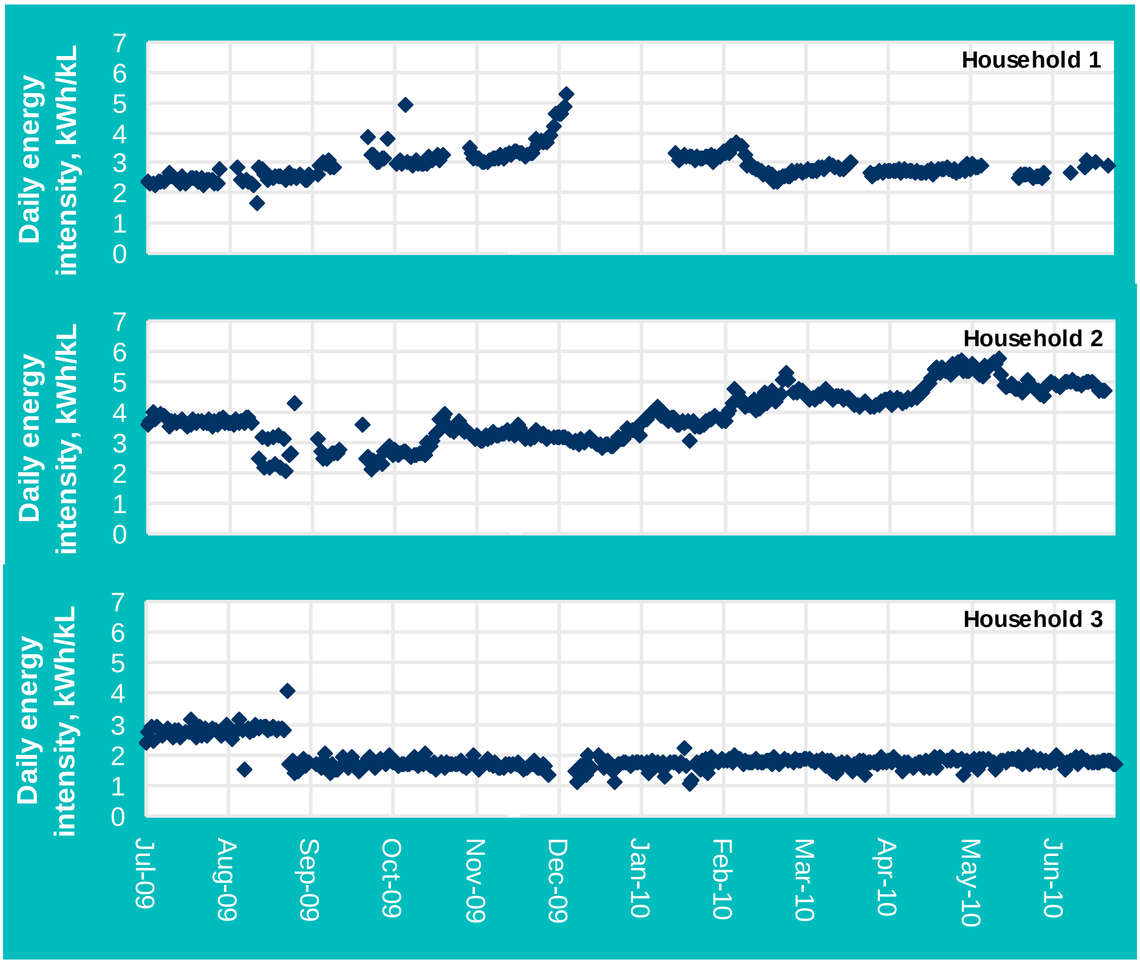

Figure 29: Unstable energy intensity trends for four households over the analysis period

5.3.6 Impact of pressure tanks on results

Pressure tanks provide a small amount of pressurised storage. This storage reduces the frequency of pumping events as pumping only occurs when the tank empties meaning that the pump operates at higher efficiency to refill the pressure tank.

The use of pressure tanks reduces total energy demand by reducing energy intensity for demands that occur at low flow rates. For rainwater tanks this is critical because at least half of demand occurs at a flow rate lower than 10 L per minute (for more information see section 4.2).

In the sample, two households had pressure tanks. The impact of pressure tanks on their intensity is discussed in the following case study.

Case study: Pressure tanks have been found to reduce energy intensity

This case study shows the effects of pressure tanks on energy intensity for two households

Household 1 has a small pressure tank (2L). This household had predominantly large use events (see Figure 30) with almost 80% of use being water use events above 50L.

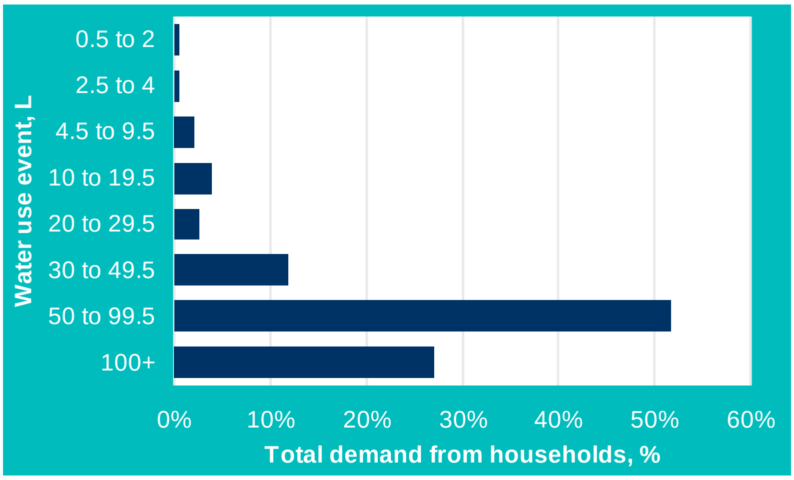

Figure 30: Household 1 demand breakdown by water use event (L) and picture of pressure tank set-up including the red pressure tank (R)

Figure 31 shows that the energy intensity for the pump compared with the specifications. Energy intensity was fairly constant for the pump regardless of flow except at volumes below the pressure tank capacity where energy intensity rises. It shows the reduced energy intensity from that expected from the specifications at flows below 10 L in a minute.

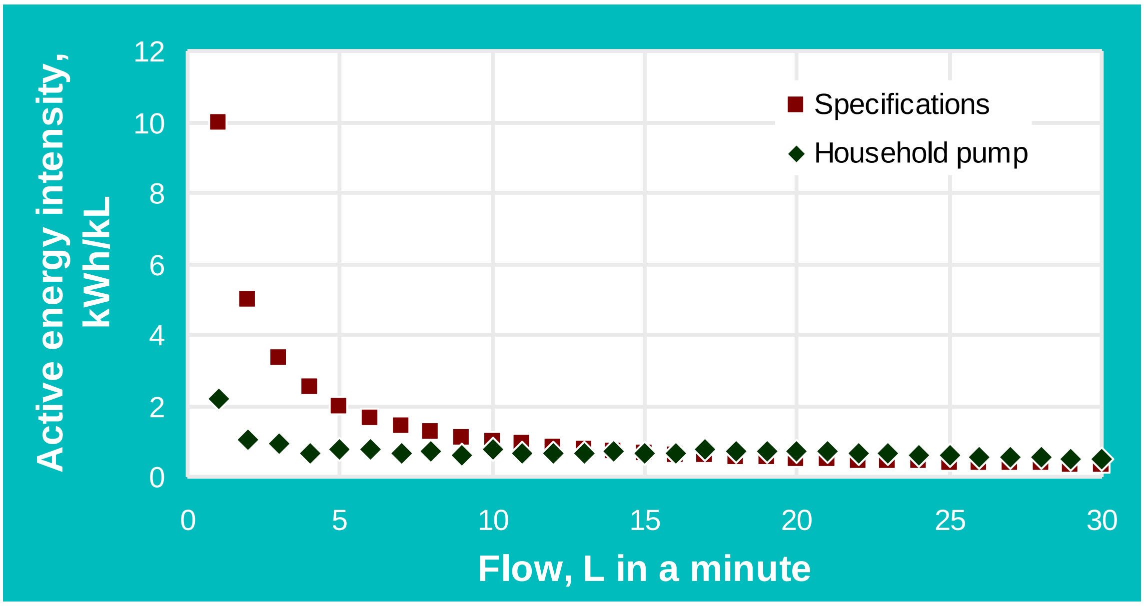

Figure 31: Pump curve for household 1 with a small pressure tank

Household 2 has a pressure tank of larger volume (8L). This household had a mostly small water use events (toilet flushing) with some moderate size events (see **Figure 32**).

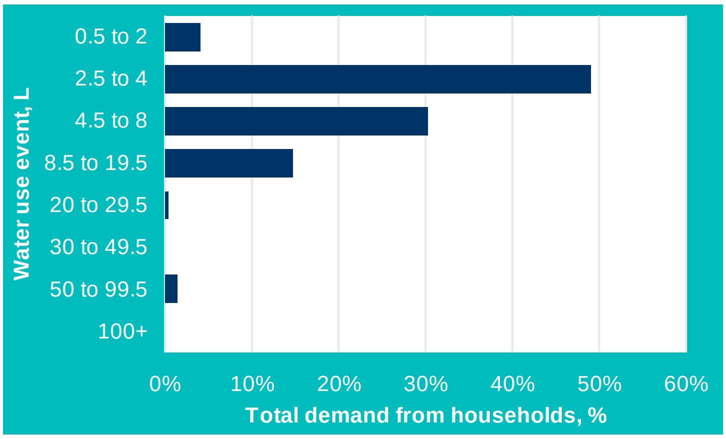

Figure 32: Household 3 demand breakdown by water use event (L) and picture of pressure tank set-up including the yellow pressure tank (R)

Figure 33 shows that the energy intensity improved at flows greater than the size of the pressure tank but was fairly constant (but higher) below the pressure tank volume. This indicates that while the pressure tank is reducing energy intensity at low flow rates, the pumping event to fill the pressure tank is not operating at the optimal energy intensity rate. It is likely the pressure vessel is operating at a restricted flow rate

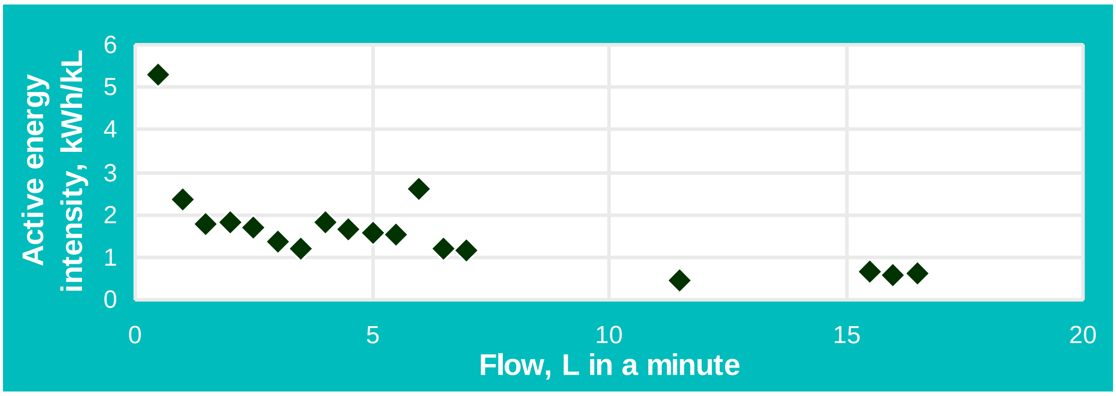

Figure 33: Pump curve for household 2 with a larger pressure tank

The case study above shows that pressure tank can have benefits in reducing overall energy intensity. Household 1 even with a small pressure tank (2L) appears to be achieving a levelling of energy intensity by ensuring that pumping always occurs at a reasonable rate and volume. Household 2 shows that savings from a pressure tank can be limited where the flow to the pressure tank is restricted in some way.

5.3.7 Seasonal fluctuations in energy demand and intensity

The fluctuations in seasonal demand (discussed in 3.3.5) appear to have an impact on energy intensity (see Figure 34). During the summer months, average energy intensity decreases from above 2 kWh/kL in April to June and falls to almost 1.5 kWh/kL for November and December. This is primarily because larger pumping events associated with irrigation demands operate at a greater energy efficiency (as discussed in Section 5.3.3).

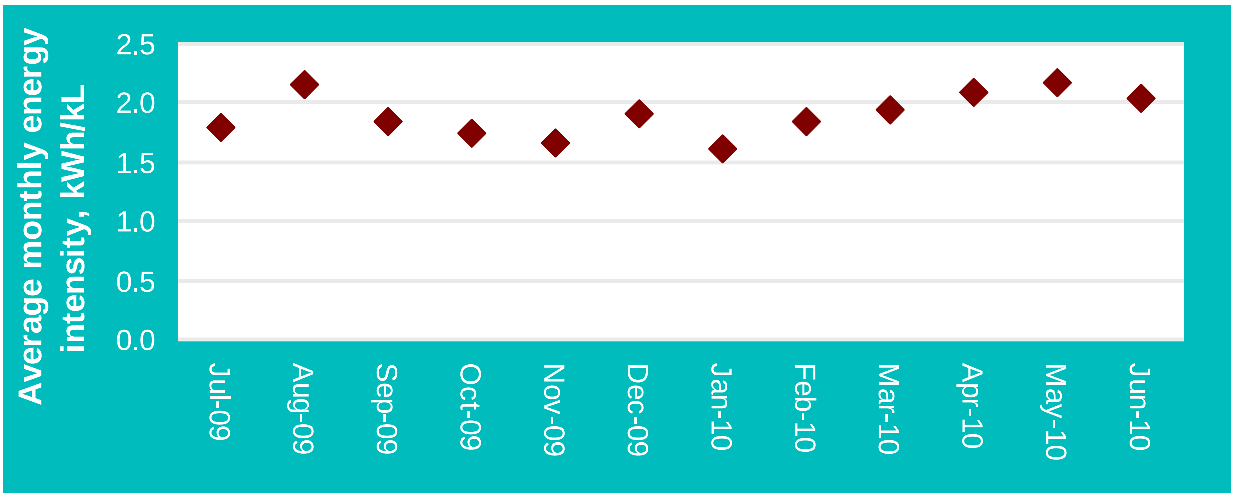

Figure 34: Trend in average monthly energy intensity

5.4 A case study of a poorly performing household for pump energy

The following section is a further investigation into why a household in the study had significantly higher energy intensity than other households. It relates to the discussions around pump energy intensity curves and flow rates.

The household has a submersible pump with switching device connected to a 3,500 L water tank that has a roof catchment area of 289 m^2. There are 3 people in the household with 2 4.5/3L toilets connected to the rainwater tank and a potential connection to washing machine.

As can be seen in Figure 35, the household has a filter after the switching device.

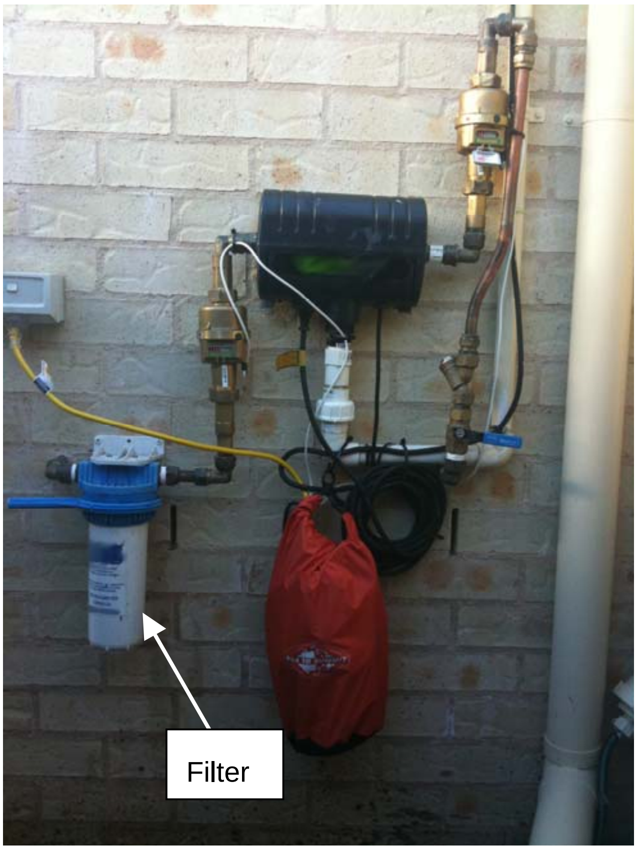

Figure 35: Switching device set-up for the household with highest energy intensity

Figure 36 shows that demand in the household is predominantly for toilet flushing with a couple of possible washing machine uses identified in the data set.

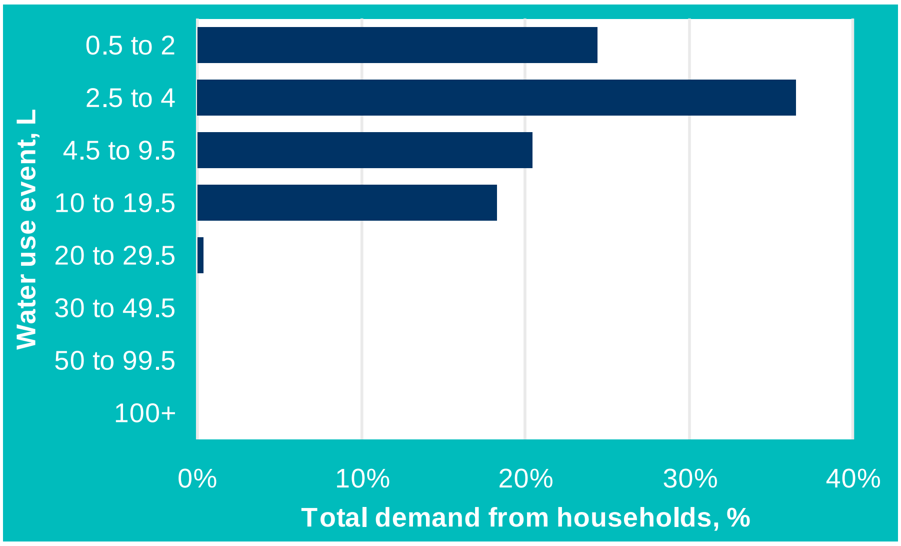

Figure 36: Water use event profile for the household with highest energy intensity

Looking at the frequency of different flow events occurring, it can be seen in Figure 37 that the majority of events occurred at either 0.5 L in a minute or 1 L in a minute.

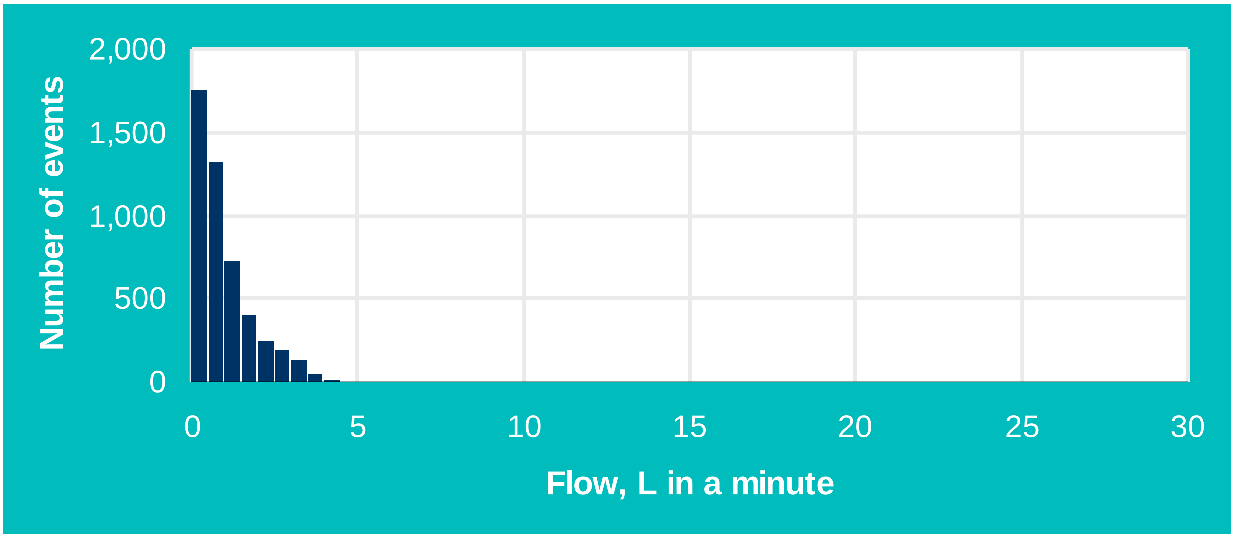

Figure 37: Incidences of flow events for the household with highest energy intensity

The curve in Figure 38 shows that at these low flow rates, the pump appears to operate at very high energy intensity compared with the average. This explains why the household is operating at such high intensity.

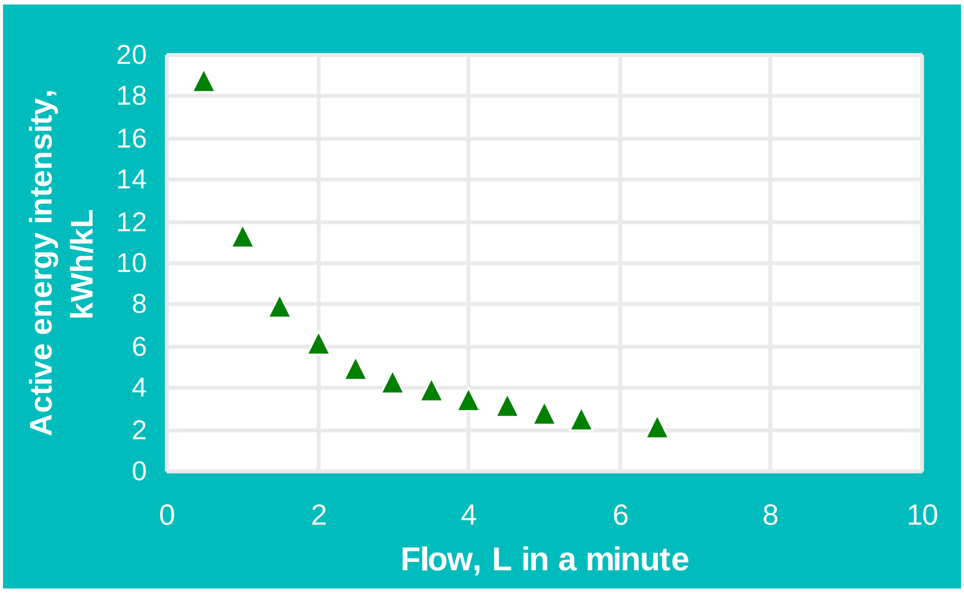

Figure 38: Energy energy intensity curve for the household with highest energy intensity

Further investigations into why it is operating so inefficiently, the household water use during a pumping event was analysed at high resolution. Figure 39 shows that a 4.5 L flush can take up to 5 minutes to completely refill. This indicates that the flow must be restricted in some way as most toilets in the study filled in less than a minute.

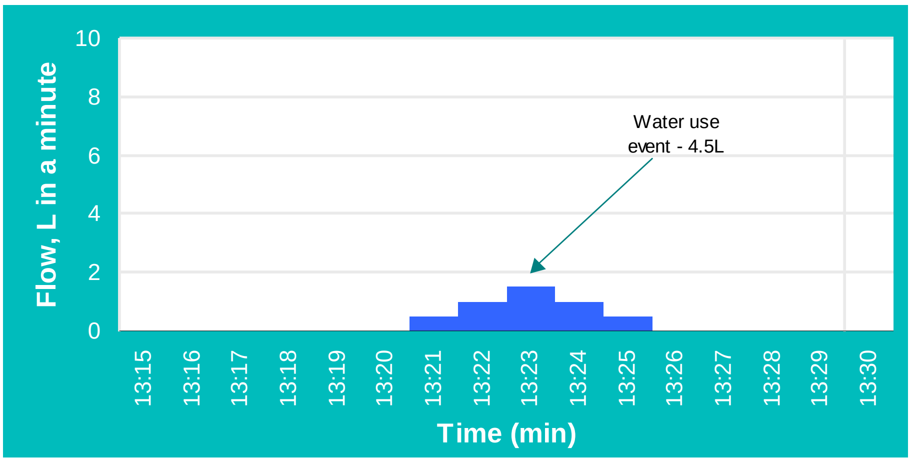

Figure 39: One-minute interval data showing a toilet flush event over 5 minutes

Given that flow restriction appears to occur both for toilet use and washing machine use, it appears that the filter must be flow limiting the pumping rate due to it being clogged, as can be seen in the following photograph.

Figure 40: Clogged water filter limiting flow from rainwater tank pump in highest energy intensity household

It appears that the filter limited the flow more and more over time until it was fixed. Figure 41 shows the energy intensity increasing from around 5 kWh/kL in October to more than 30 kWh/kL in January. It appears to have been fixed before operating again in April.

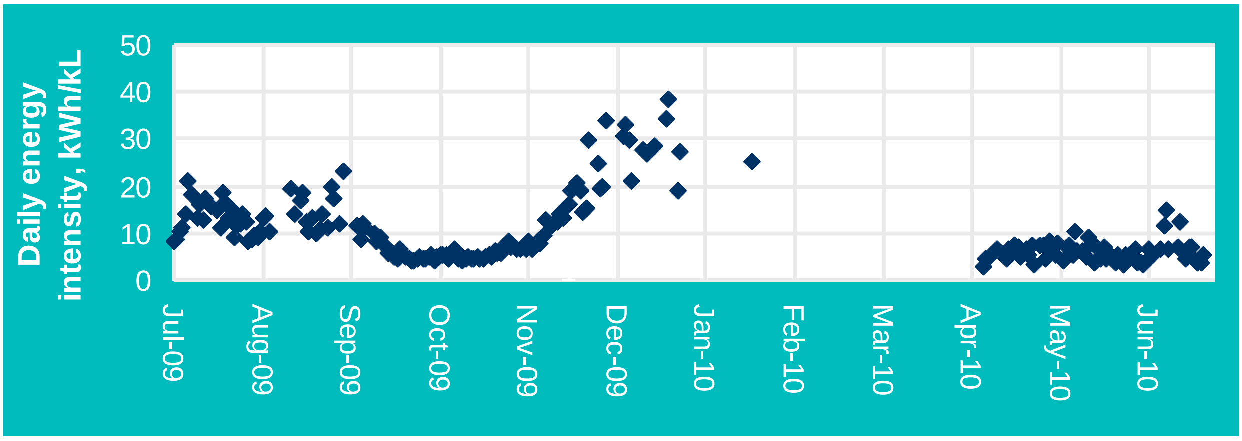

Figure 41: Energy intensity trend for highest energy intensity household (note the y-axis scale)

6 Conclusions

6.1 Summary of findings

A summary of the findings from the study follows:

- Rainwater tanks installed as required by NSW water efficiency regulations are, in the majority of cases, saving an average of 38 kL of water per household per year and up to 96 kL per household per year. These savings reflect the large tank sizes and large roof areas connected at many of the households and are larger than other study findings for urban rainwater tanks (refer Appendix).
- Demand for rainwater by these households is 30% of their total demand or approximately 59 kL per year.
- Rainwater tanks are reducing drinking water use from mains supply in these households by on average 21% by substituting rainwater for drinking water for alternative water uses.
- Total annual rainfall during the monitoring period was approximately 20% lower than the long-term average rainfall. Rainwater tank savings detailed above are likely to be an underestimate of long-term savings, especially for high demand households.
- Average roof area connected for the households from the field study was approximately 210 m^2. This is likely to be higher than for households who retrofit tanks, as it is easier to connect stormwater systems in new homes.
- Some households were found to have connected less roof area than required under the regulation. For one household, this led to reduced water savings of 12 kL per year.
- Average tank size for the sample from the field study was approximately 4,200 L.
- Some tanks were found to be underperforming for expected water savings when actual savings were compared with modelled savings. The likely cause is that the potable top-up level was set too high, reducing the effective capacity of the tank. A case study showed that for a single household this was found to reduce savings by 18 kL per year.
- There were a number of households in the sample that had reduced water savings due to some end uses (washing machine, toilet or outdoor uses) not being connected or not using rainwater. For one household, if outdoor irrigation events used rainwater, water savings would have increased by 18 kL per year.
- Seasonal demand for rainwater tank connected uses was found to be similar to that expected for irrigation connected end uses. The majority of the seasonal demand appears to have occurred as top-up rather than rainwater use. November 2009 for Sydney was very dry, meaning that many tanks emptied and irrigation use increased during the November and December period in response to the dry period.
- For households in the study, rainwater tank performance did not differ significantly between households in the higher rainfall east and lower rainfall west areas of Sydney. Western households rainwater met 69% of connected demand while eastern households only met 63% of demand. The performance of lower rainfall western households can be explained by the larger tank size and larger roof area required by regulation for western properties.
- Western households saved less than eastern households, 36 kL per year and 43 kL per year respectively, primarily due to lower overall household demand in the west (west 52 kL per year compared with east 68 kL per year).

- Energy use by tank pumps was on average 78 kWh per household per year, or approximately $15 per household per year.
- Energy pump intensity, which is energy use per rainwater saved, was highly variable due to a number of factors, in particular pump choice and demand profile.
- Median energy intensity was 1.48 kWh per kL. The average energy intensity was significantly higher, 2.08 kWh per kL, due to the presence of a small number of households with relatively high energy intensity.
- Active pumping energy intensity (energy use directly related to water use) was found to be less variable, with a median of 1.42 kWh per kL and an average of 1.83 kWh per kL.
- Measurable dormant (or stand-by) energy use was generally low with a median energy use of 10 Wh per day (or approximately 4 kWh/year).
- A few households were found to have significant dormant energy use of up to 8 Wh per minute. A possible cause of this high dormant energy use is a leak below the threshold of the water meter. This would need to be further investigated.
- Rainwater tank pumps were found to operate close to specifications (when known) with efficiencies between 55% and 70%, with the majority of pumps operating at approximately 65%.
- Pump curves show that pump efficiency at lower flow rates varied significantly. On average, submersible pumps performed worse than above ground pumps at low flow rates. At high flow rates, there was minimal difference in performance. This indicates that submersible pumps are generally sized for higher flows due to lower efficiencies at low flow rates.
- The average maximum flow was 15.5 L in a minute. At higher flows, this value would closely reflect flow rate.
- The majority of households' maximum flows were between 10 L in a minute to 22 L in a minute. There was no significant difference in achieved flow between submersible and above ground pumps. This shows that despite these submersible pumps being sized for larger flows, actual achieved flow rate did not differ in the sample.
- Low flow use dominated household use. More than 75% of flows (L recorded in a minute) were 10 L or less, and 50% were 6 L or less.
- Flows of more than 15 L in a minute account for less than 2% of the flow volume. This is despite some pumps being sized to achieve high flows. Around 50% of the flow volume occurs between flows 5 L in a minute and 15 L in a minute.
- The dominant water use events (continuous water demands from the tank over a period), on a volume basis were approximately: 30% of demand for 4.5 to 9L events, which are likely to be full flush toilet events; 15% of demand for events between 50 an 99L, which are likely to be mostly washing machine events; and 20% of demand for large events (99L or more), a mixture of some inefficient washing machine events but mostly irrigation and other outdoor uses.
- In order of median energy intensity for end uses: large events (irrigations and other outdoor uses) are most efficient (1.20 kWh/kL), followed by washing machine events (1.29 kWh/kL), full flush events (1.84 kWh/kL) and half-flush events (2.08 kWh/kL). This is due to flow rate significantly affecting energy efficiency, with larger events usually typically having higher flows. This order is not consistent for all households, with some household showing higher efficiency for washing machines.
- The differences between end uses efficiency is less significant for well performing pumps.

- Pressure tanks appear to successfully reduce energy intensity at lower flow rates. The energy efficiency benefits appear to be affected by the flow rate at which the pressure tank fills.
- Filters appear to affect effective flow rate from pumps decreasing their pumping energy efficiency.

6.2 Implications of results

6.2.1 Implication of results on water savings

Rainwater tanks appear to be successfully reducing water use for new homes although these benefits need to be compared with installation costs before a decision to install rainwater tanks occurs. Rainwater tanks are helping the households in the study successfully reduce their water use to below 200 kL per year.

Rainwater tanks have been shown to save water, on average 39 kL per year or 20% of total household demand. Rainwater is meeting approximately 60% of rainwater tank-connected demands. Due to the study period having lower rainfall than average, the savings are likely to be an underestimate of the potential long-term water savings.

Minimal difference was found for rainwater tank performance between coastal and inland tanks despite differences in rainfall. This implies that BASIX is effective in increasing water savings in drier areas.

Although, it would not be practicable for rainwater tanks to meet 100% of rainwater tank-connected demand, due to the low reliability of rainwater supply from rainfall events, a number of easy-to-do opportunities to improve the efficiency of rainwater tanks have been identified that would increase water savings.

The majority of easy-win opportunities relate to its configuration at set-up. Where a rainwater tank has been set-up as per its requirements by BASIX, the tank has been found to successfully save water as expected from rainwater modelling.

As such, improved compliance with regulatory connection requirements would improve rainwater tank performance. A number of households have been identified where:

- End uses are not connected as was required, which is particularly important for outdoor tap connections that involve large water volumes at low energy intensity, or
- Tank sizes and roof areas are less than required, reducing the amount of available rainwater for connected uses.

There also are a few opportunities to reduce issues to improve customer satisfaction by improved tank configuration:

- Correct selection of pumps to improve the reliability of rainwater tanks for general householder use. There were a few properties where rainwater tanks were not operational due to pumps that had stopped working or the householder noticed weren’t operating efficiently.
- Improve set-up to ensure adequate water quality from the rainwater tank and improve customer awareness of water quality. A number of households with rainwater connections to washing machines saved lower amounts of water than expected. This was evidenced by the missing washing machine demands in a number of households monitoring results and a number of householders said in surveys that they “switch off” their tank before a washing machine use due to issues with discoloured/dirty water.

It is recommended that rainwater tank performance be monitored following a longer operational period than 2 years to confirm that these savings will be maintained or return to the same households at a later date.

6.2.2 Implication of results on rainwater tank pump energy use

On a single household perspective, rainwater tank pumps consume only a small amount of energy. The average energy use of 78 kWh/year or approximately $15 per year is only a small percentage of energy costs for a household and is more than offset by the water cost savings.

From a system-wide perspective, energy use, expressed as energy intensity (kWh/kL), may become a more important factor for water authorities and environmental regulators due to the significant numbers of rainwater tanks that are being installed in new homes as part of environmental regulations.

This study has shown that there is wide variability in pump performance for energy intensity. The average pump energy intensity was 2.08 kWh/kL with a significantly lower median of 1.48 kWh/kL. This compares favourably with: current desalination approaches, typically 3 to 4 kWh/kL; equivalent or slightly worse than centralised recycled water schemes, typically 1 to 2 kWh/kL; and significantly worse than average surface water supply (eg dams, rivers), which is currently less than 0.3 kW/kL. Although, surface water supply energy intensity in Sydney varies significantly depending on topography, with the majority of urban fringe development occurring in areas where centralised water supply will be closer to 0.5 to 1 kWh/kL.

There are a number of opportunities to significantly reduce the average and median energy intensity of rainwater tank pumps to levels equivalent or better than central surface water supply for some development areas.

Primarily, this requires the correct selection of rainwater tank pumps to fit the demand profile for new urban homes. This is an easy change to achieve at the time of installation.

It was found that based on pump selection alone, median energy intensity could have varied from 0.68 kWh/kL if all households selected the best performing pump to 2.4 kW/kL if all households selected the worst performing pump.

The variation in energy intensity was identified as being primarily due to the differing efficiency of pumps at low flow rates. Low flow rates occur when the flow is restricted, such as due to restrictions in toilet and washing machine fill rates. The median flow for the households in the study was 5 L in a minute, which equates to a flow rate of around 5 to 10 L in a minute. Less than 2% of the demand was for flow rates that exceeded 15 L/min.

The households in the study were found to use their tanks for toilets and washing machine use typically at a flow rate less than 10 L/minute. Only 20% of demand was for outdoor higher flow rate demands at an average of about 15 to 20 L/min. This is likely to be consistent with modern urban homes that have smaller garden sizes due to smaller lot sizes and bigger houses.

On this basis, it is important that when selecting pumps that they are sized to be efficient at flow rates at around 5L/min, while still catering for flow rates of up to about 20 L/min.

The other major opportunity to improve energy efficiency of rainwater tanks is an improved method for managing stand-by or dormant energy use. While stand-by energy use was identified as being generally low, around 4 kWh per year on average, there were a small number of households where stand-by or dormant energy use was significant.

It is likely that dormant energy use in these households was due to small leaks within the system causing the rainwater tank pump to continually turn on. A method for managing this is required, which may include improved customer information to identify and fix leaks or an alarm on the pump to notify the householder that there is an issue.

Filters were also identified as having the potential to reduce flow rates, and therefore increase energy intensity, by clogging due to poor maintenance. Further investigation into their use for an urban rainwater tank situation is required.

In general, the opportunity to use financial incentives to make changes to tanks after installation are small. The cost to change a pump would significantly exceed, in most instances, the opportunity cost to reduce energy use. The greater opportunity to manage the issues listed above is prior to installation by the use of education, regulations or similar.

7 References

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