Final Report

# Survey of savings and conditions of rainwater tanks

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## Important disclaimer

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# Executive Summary

Rainwater tanks are being implemented under integrated urban water management and water sensitive urban design approaches to address resource constraints, climate change and increased urbanization challenges. State, local governments and water utilities mandate and/or promote installation of rainwater tanks through regulatory and incentive mechanisms. A number of modelling approaches are available to estimate the harvesting potential of rainwater tank systems based on climate data, roof area connectivity, occupancy rate and rainwater end uses. However, only a very small number of studies have been conducted to investigate the actual rainwater usage from household tanks using on-site monitoring approaches. The long-term supply of rainwater depends upon the physical condition of household's rainwater supply system and its overall on-going maintenance. The on-going maintenance is also required to prevent public health risk by mitigating chances for waterborne diseases and breeding grounds for mosquitoes. No previous specific study has been carried out investigating the conditions of household rainwater supply systems, or at least none that is known in the literature.

This study was initiated considering lessons learned from studies conducted on mandated rainwater tanks in South East Queensland under Urban Water Security Research Alliance. Comprehensive assessment of rainwater tank systems was conducted for mains water saving, economics of rainwater supply, energy usage, water quality, community perception, possible management models for on-going operation, optimal design of rainwater tank system and inspection of rainwater tank systems to investigate compliance of local development code. Monitoring of rainwater tanks for actual rainwater usage were conducted for estimating mains water savings and the deviation from predicted values from modelling approaches.

The aim of this study was to quantify the mains water savings that could be achieved in households with rainwater tanks and investigate the condition of rainwater tank systems for any potential health risk and identifying limiting factors in their capacity for mains water saving. 21 households were instrumented for the monitoring of rainwater usage and 417 household rainwater supply systems were inspected under this study.

The selection of participants for rainwater tank metering was conducted among the volunteers from three local water utilities staff, in most cases with the capacity for separating households using rainwater for external use only, internal use only, and both internal and external uses. In a number of sites, when feasible, water meters were installed to monitor total mains water, total rainwater usage from tank, mains water top-up and garden water usage based on the household's rainwater tank system set-up. Depth meters were installed to monitor the water depth in rainwater tanks to validate rainwater usage. The pump energy usage was also monitored for estimating specific energy (kWh/kL) in rainwater supply.

To get representative sample across Melbourne metro, the selection of rainwater tanks for the condition assessment was based on considerations to keep balance in the number of tanks installed: in three water utilities areas; statistically and relatively wealthier and less wealthy suburbs; and tanks installed under rebate program, building regulations or those adopted voluntarily. The inspection of household rainwater tank covered the whole system, which included tank, tank foundation, tank overflow pipes, downpipes, sumps, auxiliary components if installed (rain-head, leaf guards, first flush device),roof, gutters, pump, pressure vessels and mains water top-up systems (either float switch or automatic/manual diverters). Basic water quality assessment by visual inspection was conducted for aesthetic considerations (complementary laboratory testing is required in order to establish the link between colour and other water quality parameters). A brief household survey was also conducted to understand participants perception on rainwater use, maintenance related issues and benefits of tank ownership.

The monitoring of 21 homes indicated the annual average rainwater consumption of 31 kL for the indoor use only households, 11 kL for outdoor use only households and 42 kL for combined indoor and outdoor use households. The pumps used 1.8 kWh/kL energy in rainwater supply. These findings were comparable to South East Queensland study where average annual rainwater consumption was 40 kL for indoor and outdoor use households and specific energy in rainwater supply was 1.52kWh/kL.

The survey of 417 households indicated that the 62% of the tanks were installed between 2007-2010 during the peak of the drought and severe water restrictions. The inspection of rainwater tanks highlighted that 13% of the tanks were leaning on one side due to uneven foundation which may increase in lateral strain and tanks can finally crack. 5% of all sites had pumps that were not working. 39% of sites had lead flashing on the roof. 25% of the tanks were not properly fitted with mesh to prevent mosquitoes to enter into the tank. Most importantly, 9% of all sites had faulty automatic switches resulting in the use of mains water only. Addressing the problems with automatic switches would increase the water savings potential of rainwater tanks.

The physical inspection of water samples found some level of discoloration in 57% of water samples and 19% of water samples had an odour. 12% of sites had mosquito larvae present in water or mosquitoes present in tank.

Moreover, participants' survey highlighted that 96% of the participants see benefits with their rainwater tanks. The most prominent benefits highlighted were: watering during restrictions (88%), reduction in water consumption (82%) and benefit to environment (71%).

The study highlights the need for further exploring the ways to manage rainwater tanks for sustainable ongoing operation. Strategies for managing rainwater tanks should consider improving the tank system installation practices, improving the level of maintenance, and development of robust long lasting simple technologies including simple alarms to alert households for their attention.

## Acronyms

| Acronym / Term | Explanation |
|---|---|
| BMT WBM | Sub-contractor employed for installing metering equipment. http://www.bmtwbm.com/ |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency. |
| CWW | City West Water; one of Melbourne's three water retailers. |
| EU | The energy usage/requirement to pump water from the rainwater tank system into designated household end uses was also monitored in order to determine the energy efficiency of each system and to correlate to the factors influencing the energy efficiency, such as top-up type, water supply/demand patterns and pump suitability, etc. |
| GL | Volume unit dimension, Giga Liter, i.e. 1,000,000,000 liters. |
| GT | External water usage or water supply to garden tap. The GT stream is the water supply from rainwater tank to external garden taps installed for outdoor gardening or car washing purposes. All garden taps supplied water from the plumbed rainwater tank systems at the monitored households. The water supply to the garden taps was also monitored to determine external end-use water demand. |
| kL | Volume unit, Kilo Liter, i.e. 1,000 liters |
| kWh | Energy unit, Kilo-Watt-Hour, i.e. based on an effect of 1 kW applied over one hour. This is the standard measurement for which householders are being charged for electricity with a price in Melbourne typically in the range of 20-35c per kWh. |
| ML | Volume unit, Mega Liter, i.e. 1,000,000 liters. |
| MWTU | The household plumbed rainwater tank system incorporates mains water top-up or an automatic switch, which prevents any interruption in water supply during the absence of rainwater source. In this study, there are two types of top-up systems present. One home operate on the "trickle top-up" mechanism a larger number use "rainwater switch" mechanism, for back-up supply to their rainwater tanks. Rainwater tank systems employing the trickle top-up mechanism operate on a "float" arrangement, whereby every time there is a drop in rainwater level below a stipulated point in the rainwater tank, a fixed volume of mains water is delivered into the tank. This system is regulated by a valve, which is activated by a float, which in turn either starts or stops the mains water supply into the tank. However, in rainwater switch system, mains water bypasses both the tank and pump systems and delivers directly to the connected end-uses without entering the tank, until there is sufficient rainwater available in the tank. |

| | |
|---|---|
| SEW | South East Water; one of Melbourne’s three water retailers. |
| SWF | Smart Water Fund, together with the CSIRO the main funding agency for the project. |
| TM | The ‘total mains’ is the total potable mains water being utilized in the household, supplied from the water utility’s system measured at flow meter. In dwellings with plumbed rainwater tanks, TM is the only source of potable water supply to internal household fixtures such as showers, cooking/drinking, internal faucets and others. Rainwater is supplied to external garden taps, flushing of toilet cisterns and cold tap of wash machines, where the potable mains water acts as secondary water source when rainwater is not available. Only At sites with compatible main meters, the potable water flowing into the site is being monitored. |
| YVW | Yarra Valley Water; one of Melbourne’s three water retailers. |

# 1. Background

Rainwater Tanks are increasingly relied upon to provide some of Melbourne households' water security as the city adapts to an expected reduction in supply from dams. This trend has played out at a time of ongoing population growth and as households seeks to exert more ownership and control over their use of water and their impact on the environment. To keep up with this trend, water planners need accurate information on estimated water savings from the use of rainwater tanks. Rainwater tanks however pose new challenges to planners as the infrastructure is in private ownership, making it difficult to monitor or manage the condition of tank systems, or to accurately monitor rainwater usage.

Rainwater tanks are thought to contribute significantly to the common good: reductions in urban stormwater flows, water savings and reduced pressure on public infrastructure. A growing body of evidence indicates that in most cases this is true. On the other hand poorly maintained rainwater tanks may have very little benefits and may even contribute to greater public health risks. Therefore rainwater tanks are a type of resource that, to achieve the greatest impact, requires public cooperation and this raises new challenges for water managers. This project addresses one of the issues relating to the dilemma of private ownership of tanks, i.e. that there is a distinct lack of information about the ***condition*** and ***use*** of these assets. This project aims to address this knowledge gap.

Firstly, this project has inspected 417 water tanks to explore to what extent rainwater tanks are maintained in a good condition across the Melbourne urban landscape. Secondly, this project has monitored the potable water savings from rainwater tanks for 21 households, as a preliminary study that could later be expanded with the aim to understand actual rainwater usage. The expected outcome is to have a data set on rainwater tank conditions and to use this to inform effective policy and strategies for management of rainwater tanks. This study will investigate key risks involved with not managing rainwater tanks adequately, maximise water savings, and to help reap the benefits that household rainwater tanks can provide.

> The number of rainwater tanks in Melbourne has increased significantly in the last 10 to 15 years. An Australian Bureau of Statistics survey (2013) found that ***31% of approximately 494,000 households in Melbourne have rainwater tanks***. For Melbourne, the three dominant reasons for installations of rainwater tanks quoted in this survey were: to save water (60%), water restrictions on mains water (38%), and to save on water costs (24%). In this survey it was also found that only 29% of tanks were plumbed into the dwellings for indoor purposes.

The methodology of the project was straightforward, including four activities: M1 Develop protocol, recruit participants and install meters; M2 Undertake survey of the first 200 tanks, and analysis of data available so far; M3 Undertake survey of the next 200 tanks. M4. Analyse all data; write reports and end of project. The oversight of the program was under a technical reference group involving the four project sponsors.

The key objectives of the project were:

1. To deliver reliable data on rainwater tank conditions for a representative sample of the existing stock (417 tanks).
2. To deliver data on water use from roof-water harvesting from 21 sites.

## 1.1. Condition of household rainwater tanks

Rainwater collection systems require simple and regular monitoring and upkeep of catchment surfaces, rainwater tanks and devices at intervals ranging from 3 months to 2 years, i.e. Operation and Maintenance (O&M). The Australian standards document HB230A (Standards Australia, 2008) and a key document from Queensland Health (Queensland Health, 2007) include a comprehensive list of inspection as well as O&M practices required for rainwater tanks, as shown in Table 1. These practices are not difficult or extensive but require some level of understanding and motivation to undertake the management of rainwater tanks. There are also a large number of other guidelines available (Australian Government, 2004, Queensland Government, 2011, Queensland Health, 2002, WSAA, 2002).

**Table 1: Recommended inspection and maintenance for rainwater tanks***

| Frequency | Activity | Maintenance required |
|---|---|---|
| **3 months** | Inspect and clean gutters. | Remove leaves and debris. |
| | Inspect and clean first flush devices and leaf guards on rainheads. | Clean, repair or replace if necessary. |
| | Check screens on tank overflow outlet. | Repair or replace if necessary. |
| **6 months** | Check roof and flashings for defects and remove overhanging branches. | Repair if necessary and remove overhanging branches. |
| | Check tank for defects, screens and lids are in place and functional. | Repair if necessary. |
| | Check water quality. | Identify cause for quality change. |
| | Check rainwater taps have correct signage. | Repair or replace if necessary. |
| | Check pump for noise, pressure, leaks and acoustic enclosure if applicable. | Repair or replace if necessary |
| **Annual** | Check tank support for structural integrity. | Repair or replace if necessary |
| **2-3 years** | Check sediment level in tank, and desludge if necessary**. | Organise removal with a qualified contractor if sediments pose a risk to block tank outlet. |

***Note**: This table has been adapted from guidelines on keeping rainwater tanks safe authored by Queensland Health (Queensland Health, 2007) and Standards Australia (Standards Australia, 2008).

****Note**: HB230 (Standards Australia, 2008) recommends placing of rainwater outlets to dwellings at a minimum height to prevent uptake of sludge upon water extraction. In addition it recommends desludging at a frequency of 2-3 yrs.

It is also noted that the Victorian Department of Health recommends that reticulated drinking water is used for drinking and food preparation in areas where it is provided (Department of Health (Victoria), 2014)[1]. The reason provides is that the quality of rainwater is generally not as reliable as mains supplies, in terms of water quality, because mains water supplies have been treated to a level that is safe for human consumption. The Department of Health also notes that consideration should be taken for rainwater uses within the home. Plumbing rainwater within the home for laundry and toilet flushing only will minimise the risk of ingestion.

At present, householders have the responsibility for managing their rainwater tanks, thus they need to know how to undertake required O&M tasks. It was also found in a recent survey by the Australian Bureau of Statistics (Australian Bureau of Statistics, 2013) that only 58% of survey respondents with a rainwater tank in Melbourne claimed to undertake any kind of rainwater tank maintenance; and only 48% claimed to clean gutters, 26% checked/repaired inlets for insect proofing, 22% checked pipe work and connections, 20% checked or cleaned for sediments and only 5% carried out any other tasks. In 80% of the cases when maintenance was undertaken, it was carried out by the householder himself/herself.

It is noted however that householders have no legal obligation to undertake maintenance other than to minimize public health risks, and so the motivation to undertake the required tasks is of critical importance. The amount of scientific data on the practices and motivations of householders is limited, but some studies are available on these issues in South East Queensland (Gardiner, 2009, Gardiner, 2010, Tilbrook, 2009, Gardiner et al., 2008, Mankad et al., 2013) although none relate much to the issue of ensuring the condition of tanks.

It has previously been found that upkeep and maintenance of rainwater tanks is closely linked to owners' level of engagement with and knowledge of their systems (Gardiner, 2010). In rural and remote areas where households depend solely on rainwater for their water needs there is a long history of rainwater use for all purposes, including drinking, and a track record of appropriate maintenance. However, in urban areas reticulated water supply is in most cases the main source of water; and rainwater is primarily connected to garden tap, laundry and/or toilet cistern. In such circumstances, rainwater tanks systems are typically fitted with mains water back-up to ensure continuous water supply. Unsurprisingly in such circumstances, there is significant variability in the understanding of rainwater risks and attitudes towards maintenance (Gardiner, 2009, Gardiner, 2010, Gardiner et al., 2008).

During 2007-2008, (Gardiner, 2010) conducted a survey of 1051 people in South East Queensland and verified that although 95% of tanks owners reported confidence in managing their tanks, a significant number did not conduct proper maintenance. For instance, 50% of the sample of mandated tank owners reported never having conducted maintenance such as cleaning of gutters or screens, inspection of the inside of the tank, or only did so if a problem was detected (Gardiner, 2010). It seems likely that a key factor in

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[1] Further information from the Department of Health can be found here: http://www.health.vic.gov.au/water/privatedrinking/rainwater.htm

these findings is that the tanks were relatively newly installed, and that maintenance requirements would therefore be limited.

White (White, 2010, White, 2009) conducted a survey of 279 South East Queensland households with rainwater tanks regarding O&M practices and concluded that maintenance of rainwater tanks was adequate, with tank owners reporting on average 6.2 hour per year on gutter maintenance, with 76% performing self-maintenance, 12% relying on professional service and 12% relying on visiting friends or family. However, it was also reported that long-term behaviour would be difficult to gauge as the majority of tanks were less than 3 years old and 86% less than 1 year old at the time of that survey (White, 2009).

Tilbrook et al. (Tilbrook, 2009) undertook a survey of 145 homes in Lake Macquarie in New South Wales, Australia, where rainwater tanks are part of the mandated BASIX program for achieving water savings. Most tanks were installed in 2005 and the survey was undertaken in 2009, so the tanks in question were approximately 4 years old. One of the thematic areas of the survey was on the issue of tank knowledge and maintenance. More than 50% of respondents rated their knowledge of the required maintenance tasks as poor. Some of those who considered themselves to have good or fair knowledge of rainwater tank maintenance also adjusted their response after answering the following maintenance questions, saying that they had less knowledge than first anticipated. It was furthermore found that less than half the respondents carry out regular maintenance on the gutters (32%), the first flush device (23%), and the inlet on the tank (39%). Nearly 30% of respondents said they had gutter guard on their gutters and thus had not provided any maintenance to the gutters. Only two respondents said that they had desludged their tank. The most commonly occurring problems occurring were with pumps installation and water quality.

Tucker et al. (2011) have undertaken a larger scale phone survey of 1,984 households in South East Queensland to provide greater insights into attitudes and behaviours of rainwater tank owners. A number of insights were gained relating to the motivation for owning and using household rainwater tanks, i.e. participants with mandated rainwater tanks were found to have lower levels of motivation than retrofitters suggesting that they may experience a lack of control and independence when relating to their tank and subsequently their drive to engage in maintenance behaviour may lack self-directed motivation, and O&M may hence be seen as a meaningless activity. The authors note (Tucker et al., 2011):

> *The message from this finding is that among the mandated sample, people felt as though they did not know enough about rainwater tank maintenance and they were not willing to put in the effort to find out more or to engage in many of the maintenance behaviours required. This suggests that greater education is needed among those who install rainwater tanks or other decentralised systems on their property as part of a government mandate, rather than as an individual choice to do so. The subject of "choice" seems an important one when dealing with psychological motivation that will ultimately drive householders' behaviour.*

Whilst a number of surveys have been undertaken, their focuses of these surveys have varied, and the results from surveys have to some extent been inconclusive. Only Tucker et al. (2011) have really explored motivations and the psychology of householders in relation to rainwater tanks, and there is a significant need for better understanding those issues. The motivation to undertake O&M behaviours seems variable, and subject to complex socio-psychological factors, and hence strongly contextual and dynamic. There seems to be some important factors that do contribute to motivation, including education, providing opportunity for choice, and a perception of achieving private and public goals. What works in terms of motivating householders in one community however, may not necessarily work in another community. Therefore, Moglia and colleagues (Moglia et al., 2011, Moglia et al., 2012, Moglia et al., 2013a, Moglia et al., 2013b) suggested that an adaptive approach to management would be appropriate in such cases. In another study, Sharma *et al*. (2012) have highlighted inadequate operation and maintenance as a major impediment in the uptake of alternative water systems. In a more recent development, the Australian Bureau of Statistics has started to collect data in relation to household management of their rainwater tanks (Australian Bureau of Statistics, 2013).

It appears that rainwater tanks have been introduced into the urban landscape in Australia with the optimistic view that householders, once adopting this technology, will adequately maintain their tanks. Recent research into the motivations of householders to undertake basic O&M tasks however, indicate that sustaining this motivation over a long period of time is difficult, especially in situations when they had no influence in the decision to install a tank, as is the case with mandated tanks (Tucker et al., 2011). It has been found that institutionally, in parts of Australia, the policy considerations end at the time when householders take ownership and responsibility of their tanks. Transfer of ownership is not dealt with in policy, and there is no policy or requirements on O&M of tanks, other than relatively vague requirements to minimise public health risks, of which much of the community is probably not aware. At the same time, stakeholders and community members alike have a tendency to baulk at the idea of greater state control of what is in essence private property. The dilemma is of course that a resource that is privately owned is important for public good purposes, a modern-day version of Hardin's Tragedy of the Common's (Hardin, 1968) where there is a classic clash between libertarian views of property rights and economic freedoms, and the need for collectively collaborating for a common good as described by Sheard (2010); in this case ensuring the urban water supply. The outcome, in terms of the condition of the asset stock of rainwater tanks, is essentially unknown, as no wide-ranging surveys of their conditions have been undertaken. When approaching stakeholders about the feasibility of undertaking such surveys, concerns are raised regarding the reaction of the community. Without further research, uncertainty about condition of rainwater tank remains, and therefore one has to rely on judgments.

Judgments on rainwater tank conditions, in South East Queensland at least, paint a problematic picture. Based on an email based survey, plumbers' as well as water professional judgments indicate problems with pumps in as much as 46% of cases, which is hopefully the worst case scenario, and even if actual numbers are more aligned with the most optimistic plumbers' judgments, then 10% of tanks have problems with pumps, which is still a significant problem (Moglia et al., 2012, Moglia et al., 2013b). Plumbers' judgments are likely to be biased to those that they have experience with; which is likely to be in such bad condition that plumbers are called out to the job.

We also note that problems with rainwater tank conditions may provide part of the explanation for lower than expected water savings as has been observed in other studies (Beal et al., 2012, Chong et al., 2011). Perhaps even more worrying is that plumbers and professionals judge that as much as a third of tanks may have broken or removed mosquito meshing, which poses a significant health risk, as it provides plenty of opportunity for mosquitoes to breed and become disease transmitting vectors in the urban landscape. Therefore, a large survey is underway, exploring the potential for mosquito breeding in household backyards in the South East Queensland region (Hurst, T 2011, personal communication 23rd September). Microbiological water quality also seems to be an issue, at least if water is to be used for drinking, which has already been flagged by Ahmed and colleagues (Ahmed et al., 2010, Ahmed et al., 2012) as a problem with rainwater harvesting in the South East Queensland urban region.

Rainwater tanks are an increasingly common feature of urban water planning in Australia and globally. Maintaining a tank is not difficult, but it has to be done, or the tank will deteriorate. Deterioration of the tank, if not attended to, will lead to broken down pumps impacts on potential for water savings especially if the system is plumbed into the house and in turn, on local strategic water planning; inadequate mosquito meshing increasing the risk of mosquito born disease in the urban landscape; water quality concerns limiting the usefulness of the water source to non-potable applications; and problems with plumbing, first flush devices, switching valves and gutters will limit the potential water capture by tanks (Moglia et al., 2013a).

> Previous rainwater tank studies have been using either flow meters or depth gauges for estimating rainwater use. This study uses a combination of both and this allows for cross-checking results against each other and thus supporting the validation and calibration of approaches against each other. The analysis per se is however not part of the scope for this project.

*There is currently no satisfactory data on the condition of rainwater tanks, and such data is urgently needed. In its place, judgments by plumbers, tank owners and water professionals paint a bleak picture, with potentially nearly half of pumps expected to be broken, and over a third of mosquito meshing inadequate, as well as a range of other problems.*

Hopefully, problems are not as bad as this indicates, but this reiterates the need for collecting better data. If such data will show that there is indeed a problem, as is probably expected, then there is a need for urgent review of the current management paradigm for rainwater tanks. Policy currently does not cover tank management after it passes into private ownership, but this may somehow need to be addressed in some way; preferably in a way that maintains and increases householders' motivation for engaging in tank maintenance, rather than diminishes it.

## 1.2. Metering studies

In Australia where concerns about urban water scarcity is an ongoing issue in many cities, there have been a number of water end-use studies, most notably those by Roberts (2005), Willis et al (2009) and Umapathi et al (2013). The focus of these studies has been to understand patterns of water use, and the contributions to demand from various types of end-uses. End-use measurement also feeds into end-use modelling as reviewed by

Rathnayaka et al (2011) for which a number of purposes of models exist such as estimate impact of climate on water use (Moglia et al., 2009), forecasting residential water demand (Gato et al., 2007, Zhou et al., 2002), understanding water conservation behaviour (Rixon et al., 2006) and infrastructure planning (Gurung et al., 2014); as well as a way to understand how to reduce peak water demand (Carragher et al., 2012).

In terms of end-use measurement, the study by Umapathi et al (2013) is particularly pertinent due to its strong focus on rainwater tanks. Furthermore, Burns et al (2014) has also measured tank water depth to estimate rainwater usage, in order to assess the performance of rainwater tanks in terms of their ability to reduce potable mains water usage and to retain run-off from rainfall events and thus reduce the volume and frequency of stormwater run-off. Other recent studies (Knights et al., 2012, Talebpour et al., 2014) have measured the usage of rainwater to evaluate energy usage from rainwater tanks, and reduction in pollution loads to receiving environments.

A particularly contentious issue in relation to rainwater tanks is the estimation of the average rainwater yield from a tank system. This issue rose to particular prominence in South East Queensland where it became a topic of political issue. Numerous researchers thus attempted to achieve accurate estimates of the yield (Coultas et al., 2011, Chong et al., 2011, Umapathi et al., 2012, Umapathi et al., 2013). The estimates of yields impacts on cost effectiveness calculations (Binney and Macintyre, 2012). Eventually, perceptions of poor cost effectiveness of tank systems lead to the political decision to scrap the requirements of the Queensland Development Code to install rainwater tanks with all new houses.

Related to the estimation of rainwater tank yields, in a previous study, CSIRO successfully monitored the rainwater usage in South East Queensland in order to get more accurate estimates of water savings from rainwater tanks (Umapathi et al., 2012, Umapathi et al., 2013). Whilst the previous study was successful, the socio-economic and climate conditions in Melbourne are different to the conditions in South East Queensland, and thus the results are also not applicable in the Victorian context. This study therefore builds on the previous study in an appropriate manner, but applies the updated methodology in the new context.

The aim of the research in South East Queensland was to investigate mains water savings achieved through mandated internally plumbed rainwater tanks in detached dwellings. Mandated rainwater tanks were installed in all new detached residential dwellings in South East Queensland to meet the requirements of the Queensland Development Code (QDC MP 4.2) which was effective from January 2007 until the legislation was repealed in February 2013. The code mandated that all detached households were required to meet a mains water savings target of 70 kilolitres per year (kL/yr). One of the acceptable measures to meet this target was considered to be the installation of a 5 kL rainwater tank connected to 100 m$^2$ roof areas which in turn is plumbed to household appliances such as washing machines cold water tap, toilets and at least one external tap. The internal fixtures connected to the rainwater tank also required a back-up to the mains water supply either through a mechanical trickle top-up or an electronic switching valve system to ensure a continuous supply of water (Department of Infrastructure and Planning (DIP), 2008). Twenty households located in four local government areas in South East Queensland: Pine Rivers, Caboolture, Redlands and Gold Coast in South East Queensland were selected for rainwater use monitoring.

The focus of the previous research was on households located in regions across South East Queensland, which have been previously been examined by several research groups (Beal et al., 2012, Chong et al., 2011) for reasons of high population density and rapid growth in new Greenfield urban residential developments. Beal et al. (2012) conducted a pair-wise statistical analysis where 1182 households with plumbed rainwater tanks were randomly paired with households without rainwater tanks, but of similar biophysical characteristics, to estimate mains water savings by comparing their water billing data for 2008. In a similar study in the same geographic areas, Chong et al. (2011) performed a benchmark analysis of 691 households with plumbed rainwater tanks using their mains water billing records and comparing them with the regional average residential water demand for the same period (years 2009 and 2010). The study by Beal et al. (2012) found an average mains water saving of 50.5 kL/household/year across three local government areas (LGAs): Pine Rivers, Gold Coast and Redlands for the year 2008. Chong et al. (2011) included Caboolture into their study of Pine Rivers, Gold Coast and Redlands, and determined a mains water savings in 2009 and 2010 of 58 kL/ household/year across the four LGAs.

However, both desktop studies indicated that the installation of a 5 kL rainwater tank connected to 100m$^2$ roof catchment area may not be sufficient to collect sufficient rainwater to meet the mains water saving target of 70 kL/ household/year. Imteaz et al. (2011) also conducted spreadsheet based water balance modelling to investigate the reliability of rainwater tanks in Melbourne and found that for a roof area of 150 m2, it was almost impossible to achieve 100% reliability (for a 2 person household). Moreover, the supply gain from increasing tank size became insignificant for tanks over 5 kL.

Several other analytical methods and modelling tools have been reported in the past to predict rainwater harvesting potential from rainwater tank systems for combinations of various end uses, connected roof catchment, and tank size (Coombes and Kuczera, 2003, Fewkes, 1999, Khastagir and Jayasuriya, 2010). Whilst modelling studies are important for understanding cause and effect and for making predictions, results obtained from such secondary research approaches need to be validated by primary data which in the case of rainwater usage warrants evaluation against experimental results. Hence, in order to determine the efficacy of household plumbed rainwater tanks, monitoring and validation are required to understand the effect of water planning strategies to address the demand on fresh water resources. The study described in this report aimed to quantify the magnitude of mains water savings achieved from plumbed household rainwater tanks.

Apart from the monitoring and analysis of water consumption in households, the study also covered the energy perspective of operating plumbed household rainwater tank systems. Earlier studies monitoring the energy consumption of small estate rainwater supply systems in Australia were conducted by Gardner et al. (2006) and Beal et al. (2012). The energy intensity of these estate-scale small water supply systems was found to be higher than centralised water supply systems, with an average value of 2.6 kWh/kL (Gardner et al., 2006). Another study conducted by Retamal et al. (2009) found that the energy intensities in rainwater tank households using rainwater for toilet flushing, laundry and outdoor water use ranged between 0.9-2.3 kWh/kL. The differences in the intensities were found to be attributed to differences in pump sizes, presence of other system components, specific end uses and water use efficiency of the appliances.

Nonetheless, Retamal et al. (2009) showed that the energy intensities in small scale decentralised systems were much smaller than that of large scale desalination plants.

The mains and rainwater consumption of a set of 20 dwellings were monitored to estimate actual water usage and volumetric reliability of rainwater tank systems. The 20 chosen homes were situated in the same regions previously studied in the work by Beal et al. (2012) and Chong et al. (2011), which were: Pine Rivers, Caboolture, Gold Coast and Redlands (Umapathi et al., 2013). The real time monitoring data of the households commenced in April 2011 and continued for a period of one year, ending in April 2012. The water supply (mains water and rainwater) and demand arising from internal and external water use in these homes were monitored, and the performance of each home in achieving water savings were analysed together with the corresponding energy consumption, which was also measured in each household.

## 1.3. Key objectives of the study

The latest surveys by metro water retailers show that around 30% of homes have rainwater tanks. The rate of ownership of rainwater tanks is likely to further increase in the future due to the ongoing support for Government's rebates as well as Victoria's legislation for new homes that requires the choice of either rainwater tank or solar hot water heater for compliance (i.e. currently to achieve a 6 star energy rating). Home owners may prefer installing rainwater tanks over solar hot water systems based on cost considerations. There are also widely held community views that rainwater tanks provide a range of environmental benefits including the reduction of stormwater peak flows and pollutant loads into waterways. Yet, the failure of tanks could mean that they are unable to fill or are always full due to lack of use, thus negating any theoretical environmental benefits. A related issue is the health hazard to the community due to possible mosquito breeding in tanks if maintenance is neglected. An understanding of how rainwater tanks contribute to the overall supply-demand balance requires two considerations: (i) yield estimates; and (ii) actual consumption of rainwater from the rainwater tank. The first may be considered to be highly tractable. Yield estimates are computationally simple from parameters such as localised rainfall, connected roof area, tank size and demand. Estimated yields however differ from real yields as they are highly dependent on use patterns that are thought to be highly variable. Furthermore, yield estimates cannot simply be taken at face value because the actual use of the rainwater depends on maintaining the rainwater tank in good condition. Failure may result from pump breakdown, tank breakdown, clogged inlet screens, sludge build-up and poor water quality.

This research application proposes to collect data on rainwater tank conditions and rainwater usage to improve the understanding of how rainwater tanks contribute to the overall supply-demand balance. It also aims to deliver data on measured water savings from rainwater tanks, to improve water savings estimates.

The key objectives of the project are:

- To deliver reliable data on rainwater tank conditions for a representative sample of the existing stock (417 tank sites were inspected).
- To deliver data on water savings from rainwater harvesting from 21 sites.

## 2. Rainwater tank condition assessment survey methodology

The rainwater tank inspection program was undertaken in 417 sites across Melbourne. The purpose of the inspections was to evaluate the condition of rainwater tanks. Each assessment involved a physical inspection of the tank system as well as a householder survey.

The tank inspection survey was undertaken in adherence with appropriate and ethical conduct requirements and to mitigate any concerns about health and safety. To promote ethical conduct and alleviate health and safety concerns, the survey was subject to:

- An ethics review and risk assessment by a CSIRO ethics review committee. The study was also required to comply with the *NHMRC National Statement on Ethical Conduct in Human Research*[2].
- Participants were asked to sign a participation consent form before participating (see Appendix A)
- Health and Safety approval, which has consisted of defining and approving a Safe Work Instruction schedule for the site inspection program (see Appendix B).

The methodology of this inspection survey is defined through the processes for:

1. Identifying and inviting participants into the survey.
2. Carrying out a survey with questions to householders.
3. Undertaking the site inspections.
4. Storing the data for further analysis.

These steps are described in further detail below.

#### 2.1.1. Sampling methodology

The methodology for getting a representative sample of rainwater tanks across Melbourne had the following goals, i.e. achieving:

- An acceptable geographical distribution of inspections across the Melbourne metropolitan area:
  - A reasonable balance in the number of tanks installed in the three water retailer zones.
  - A reasonable balance in the number of tanks in wealthier and less wealthy suburbs (as judged by average income in the most recent Australian Bureau of Statistics Census, http://www.abs.gov.au/census)
- Sufficient numbers of tank inspections of the three categories of tanks:
  1. Tanks installed on a rebate program,
  2. Tanks installed in new housing developments to comply with building regulations;
  3. Tanks that were installed outside of any rebate program or to comply with building regulations.

The reasoning for the choice of target areas was also informed by research on peoples motivations for installing tanks (Mankad et al., 2013, Brown and Davies, 2007, Gardiner et al., 2008):

- The main reason people install tanks was considered to be to protect oneself, lifestyle and property from the negative effects of water shortages. This was

[2] http://www.nhmrc.gov.au/guidelines/publications/e72

classified as the "*self-sufficiency*" driver, expected to be the primary driver in more affluent suburbs where household gardens were larger.

- Another key driver is a person's concern for environmental issues, as is present in both academic discourse and political debate. Rainwater tanks are perceived by these people as part of a group of technologies that bring environmental benefits. This was classified as the "*environmental*" driver. It could be argued that ownership of a rainwater tank in the absence of other strong drivers is an indicator of environmental concern; this however discounts the importance of normative drivers.
- Building regulations, such as the requirements for new houses, means that there are compliance reasons for houses to have rainwater tanks. This is referred to as the "*regulatory*" driver.
- Social norms were identified as an important role in how receptive householders are to rainwater tank ownership. When people believe that 'it is expected of me that I should install a rainwater tank system on my property", they are much more likely to install a tank. This is referred to as the "*normative*" driver. Mankad and colleagues (2013) identify this as an active driver in the Australian communities; however there is no data that highlights which suburbs in Melbourne this driver is prevalent. The best indicator of the "*normative"* is a high rate of rainwater tank ownership, especially when other drivers are not pronounced.
- Cultural background and political inclination have also been shown to be significant drivers in rainwater tank receptiveness, as is the case for climate change attitudes. For practical and ethical reasons, these drivers were not considered in this study.

The dominant types of drivers were based on the following assumptions.

- **The self-sufficiency driver** was assumed to be dominant in more affluent suburbs[3], and where blocks of land tended to be relatively larger and tanks were suspected to be more common.
- **The environmental driver** was assumed to be dominant in more affluent inner-city suburbs.
- **The regulatory driver** was assumed to be dominant in newly established areas where the six star rating requirements have been in place during the construction of most homes.
- **The normative driver** was assumed to be dominant in areas with high rates of rainwater tank uptake that could not be explained by the other three drivers. The difficulty of establishing this group was acknowledged, with further validation being sought from research results.

To promote the adequate spread of participants, the following tactics were employed:

- **Door knocking** in selected suburbs, and in this way inviting members in the community to participate. It was found that this method was extremely time consuming for a number of reasons including the fact that many householders are not at home during business hours, only about a third of households have a rainwater tanks, and finally some householders were difficult to convince to participate. Employing this method, only 2-3 households could be recruited each day, and this method was therefore abandoned except towards the end of the study when a greater proportion of tank systems in new developments were sought.

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[3] We make the judgment regarding how affluent a suburb is based on ABS data from the 2011census, which is available online: http://www.abs.gov.au/websitedbs/censushome.nsf/home/data?opendocument#from-banner=LN

- **Pamphlets** (see Appendix F) were distributed around target suburbs calling for volunteers to participate in the research. The number of pamphlets dropped in each area varied from around 100 to 1,000. Sometimes multiple drops would occur in the same area. The rate of response from this method was about 2-5% although this varied considerably depending on the area that was targeted. In this method, it was found that elderly and wealthier suburbs responded to a greater extent.
- **Invitation by email** for householders who had received rebates from water companies for installing their tanks. This method was quite successful with between 20% and 40% of those receiving emails choosing to participate in the study.
- **Advertising the study in various newsletters**, including local councils, and community groups. This method was also relatively successful although it is difficult to gauge exactly what percentage of the readership who decided to participate.
- **Word of mouth**: the call for volunteers also spread through word-of-mouth, and past participants passing on the call to friends and colleagues. This method of invitation was slow in the beginning but towards the end of the study, there was a steady of flow of volunteers into the study.

A monetary incentive was used to entice volunteers to participate; this was offered to all participants (a $20 voucher, primarily for groceries or hardware shops). Whilst the ideal situation would have been to have a single method of invitation, the difficulty of recruitment meant that a fair amount of pragmatism had to be employed.

### 2.1.2. Scheduling of participants

In most cases, interested participants made contact via email or through an online survey (SurveyMonkey) and were then engaged through phone and email to schedule assessments. Each assessment was given 1 hour to be completed, with a further 1 hour provided for travel time between assessments. To account for variable transport times between assessments, and assessment lengths, assessments were in most cases restricted to 10:00am, 12:00noon and 2:00pm, Monday – Friday. Some inspections were also carried out on weekends, in cases when volunteers were not able to participate at other times.

### 2.1.1. Engagement with participants

During site inspections, participants were engaged in a way that ensured the household survey and site inspection were completed in respectful manner. This involved:

- Contacting participant on the day of inspection to confirm booking.
- Clear introductions at the first point of contact, with CSIRO identification clearly visible.
- Requesting to be directed to the rainwater tank. To ensure privacy was respected, walking through the participants' house was avoided were possible.
- Leading an initial conversation with the participant, describing the research, and clarifying what would be involved in the site inspection.
- The participant was then directed to the household survey, and questions were clearly explained.
- The participant was also engaged in an initial discussion on the tank system history and any specific details about the set-up.

The survey usually took 10-20 minutes to complete and the tank assessment took 20-45 minutes to complete. Times varied depending on the complexity of the system, or the level of detail given by the volunteer and their involvement in the assessment.

Acknowledging that despite best intentions, dealing with the public may lead to complaints, study participants were informed about their ability to lodge complaint:

- Through the participation consent forms. Complaints are lodged to the CSIRO Manager for Social Responsibility and Ethics on 07 3833 5693 or by email at csshrec@csiro.au.
- Through a range of materials to submit queries to the project leader via email or phone.

To limit the liability in the case that participants claim that the surveyor has caused damaged to their property, the surveyor has taken pictures of the surrounding areas before and after the inspections. The surveyor has also been reading the relevant documentation on the appropriate conduct when undertaking surveys. No complaints have been lodged as far as the report authors are aware.

## 2.2. Householder survey

Each participant in the survey was asked to respond to a range of survey questions (as per Appendix C). Surveys were conducted in person by a trained CSIRO staff member who was present and thus able to clarify questions where required. The survey provided information on household details, rainwater use, maintenance related issues and perceived benefits of tank ownership (see details in Appendix C). The survey was designed to be completed in approximately 15 minutes, and this limited the scope of the survey. In practice the survey took 10-20 minutes to complete.

## 2.3. Site inspections

Tanks were for any faults, as per the proforma in Appendix D. Some of the key focus areas for inspections are described here.

**Risk Assessment and Hazard Identification**

An initial risk assessment was undertaken to identify potential hazards and ensure personal safety. This included engaging survey participant in a discussion about risk. If site was deemed unsafe, the assessment was discontinued. Potential Hazards that were noted:

- Potential causes of slips, trips or falls,
- Sharp objects,
- Electricity,
- Animals (dogs, snakes, spiders)
- Water (swimming pools).

**General Observations**

Initial observations of the local area were recorded and photographed. Observations focused on property details and potential sources of water contamination (Figure 3). The presence of any rainwater use signs, at either property entrance or taps was noted. Other specific observations noted were:

- Property size and type,
- House size, age and type,
- Health of garden where water is used
- Presence of swimming pool
- Overhanging trees
- Roof access for possums
- Construction zones in local area

**Rainwater Tank Characteristics**

The type, dimensions and volume of each rainwater tank on site was recorded. This information was taken from manufacturers label or measured manually. A laser measure was used to take measurements of height and width. The tank infrastructure was photographed. The overall condition of the tank and plumbing was then assessed and the tank photographed. Specifically noted was any damage, UV degradation, water level indicator functionality and the use of correct pipes and fittings. Characteristics noted:

- Type (slimline, round, etc)
- Material (polycarbonate, galvanised steel)
- Size (height, width)
- Volume

Condition issues noted:

- Holes or cracks
- UV degradation (discolouring, cracks, brittle plastic)
- Correct plumbing

**Tank Foundation**

The tank foundation material and condition was assessed (see Figure 10). A spirit level was used to determine if the tank was leaning, and visually inspected to identify how well it was placed when installed. Specific conditions noted:

- Foundation material (Concrete, Gravel, Sand, Bricks, Pre-existing footpaths etc)
- Angle (Level, off but stable, off and at risk).

**Catchment management**

The means by which water was introduced into the rainwater tank was assessed, noting the number of effective downpipes. Any auxiliary components were noted and their condition assessed. The tank inflow mesh was assessed and photographed. Mesh size was measured using a metal ruler. Volume (L) of leaf litter was described, and any damage noted. Specific issues noted:

- Direct downpipes
- Wet/charge systems
- Sumps

Auxiliary components noted:

- Rain-head, i.e. a container between the gutter and the downpipe that helps the flow of water from the roof and into the tank (see Figure 8).
- Leaf guards: a mesh to protect gutters from filling up with debris.
- First Flush Device: a device to divert the first volume of rainfall, allowing for dirt and other contamination that has accumulated on the roof to be diverted away from the tank.
- Tank guardian: additional tank screen which is easily removed and thus allowing for easy cleaning.

**Roof**

The rainwater catchment area was visually assessed using a mounted camera. The roof area connected for harvesting was estimated, and the roofing material, any potential sources of lead (Figure 5), leaf debris or animal faeces noted. Specific characteristics noted:

- Roof Area
- Roof Material (Tiles, corrugated iron, etc)
- Lead Flashing (around vents and sunroofs)
- Overhanging trees as per Figure 3 (source of leaves and animal faeces)

**Gutters**

A mounted camera (see Figure 1 and Figure 2) was used to view the inside of the gutter and within 200mm and assess its integrity and content. The height of the gutter was measured using a laser distance meter. Integrity issues noted:

- Gutter Guard
- Damage (rust, holes)
- Angle (pooling water or algae)

Content noted:

- Leaf litter
- Soot, dust, grass, building materials
- Faecal matter (Birds, possums)

**Tank overflow system**

The tanks overflow management was visually assessed, noting condition of pipe-work and if connected to stormwater (Figure 6). The condition of the mosquito mesh at overflow was also assessed. A laser distance measure was used to measure overflow height from tank base. Condition issues noted:

- Pipe connection leaks
- Flooding,

Mosquito mesh issues noted:

- Fouling
- Improperly installed (glued)
- Absent (potential access for mosquitoes or vermin)

**Pump**

Where present, the tank's pump was visually assessed, manually tested and photographed (Figure 12 and Figure 13). The pumps were checked by running them, after ensuring that power was supplied and that the pump had adequate water supply from tank (e.g. ball valve between tank and pump was open). Subsequently, a tap connected to outlet was opened or for in home connections the occupant was asked to flush the toilet. With the pump running it was checked for leaks and noises (bearing noises) or friction. Then the inspector ensured that the pump stopped running when water taps were off. There was also a check for water damage to the pump e.g. if the pump was positioned in a low area prone to flooding there was usually a trace of previous water line.

The pumps details were noted from the manufacturer's label. The height of the water intake from the tank was measured, and the diameter and condition of the pipe-work was noted. The pump was tested and issues identified by pumping water for 10 seconds. A visual inspection of the pump enclose was undertaken to determine effectiveness of sound isolation and presence of weather protection (Figure 13). By talking with survey participant, the history of the pump was ascertained.

Details noted:

- Brand (Davey, Onga, etc)
- Type (inline, sump etc)
- Flow rate (L/m or m3/hr)
- kW rating
- HP rating

Potential issues noted:

- Noises (stop/starting, dirt inside, clicking)
- Not maintaining pressure
- Leaks (connections)
- Insufficient pressure (pumping upstairs)

History noted:

- Pump age
- Past problems or repairs
- Number of past pumps

**Additional devices**
Additional devices used in the management or distribution of the harvested rainwater were visually assessed. Where present, the electronic water diverter was tested by running the pump and visually checking the 'on' light and listening to direction of water flow through the diverter. Additional devices noted:
- Inline filters
- Pressure vessels (see Figure 12)
- Mains water diverters (electronic, manual, see Figure 11)
- Mechanical float switch

**Testing switches/diverters:**

Water diverters have slightly different designs but on the whole their objective is to select mains water (on demand) when the water level within the tank reaches a minimum level, normally governed by the vertical position of a mechanical float switch. The attraction with this system is that the pump isn't used to transfer mains water, so energy savings are achieved. When electronic diverters fail, the most common scenario is that no tank water is used; an obvious indicator is that there is sufficient tank water but no pump activity. Instead it is possible to hear a trickle sound of mains water when there is a water demand placed on the system (e.g. toilet flush). In some cases, units display other fault symptoms such as regular clicking sounds similar to a relay movement and an LED flashing to indicate a fault, again with no pump activity. Symptom in other diverters includes water leaking from the housing, while still allowing only mains water use. These units are not positioned near the tank so the leakage would end up on the floor. The electronic diverters can be tested via a few different methods (depending on type):

1. Create a water demand and assess what water source used, via sound of flow and observing the LED status indicator.
2. If the pump is in use, manually close the mains water line (via valve) and check for changes in flow. Sometimes tank water and pumped mains water is being delivered mixed together; wasting energy and mains water.
3. If there is no pump activity (and there is water in the tank), manually activate the pump via the reset button, if the pump still doesn't operate a second test can be performed where the pump can be plugged directly into mains power. In all cases the pump has worked after this test, indicating a fault with the rainbank and/or float switch.

**Basic water quality assessment**
A sample of water was taken from the tank outlet and its quality assessed. To ensure sample was representative of tank water, the initial 10 seconds of flow were discarded. A white 10L bucket was then half filled and its odour, colour and particulate concentrating was visually assessed and the sample photographed (see Figure 14, Figure 15, Figure 16, Figure 17 and Figure 18).

Odour noted:
- Smells (rotting, musty, sulphur)
- Severity (no odour, intense odour, etc)

Colour noted:

- White (cloudy)
- Green (light or dark)
- Brown (light or dark)

Particulates in the water noted:
- Sediment
- Larvae

**Issues relating to protection against insects and vermin**
The tanks protection against mosquitoes was visually assessed. The condition of screen mesh at inflow, and mosquito mesh at overflow (see Figure 9) was described and any gaps or potential mosquito access identified. When possible, an internal inspection was undertaken to identify the presence of mosquito's, larvae, other insects or animals inside the tank. Other open water vessels in the vicinity were also checked for mosquito larvae.

Potential access for mosquitoes noted:
- Inflow mesh
- Gap between mesh and tank
- Overflow mesh
- Holes or cracks

Types of disruption noted:
- Mosquitoes, nematodes, other insects,
- Plant or algae growth,
- Other animals (snails, spiders, vermin etc)

**Figure 1: Mounted Camera (WiFi GoPro on a telescopic painter's pole), used to assess the condition of gutters.**

**Figure 2: Mounted Camera, attached above wheel to maintain camera at 200mm above gutter while filming.**

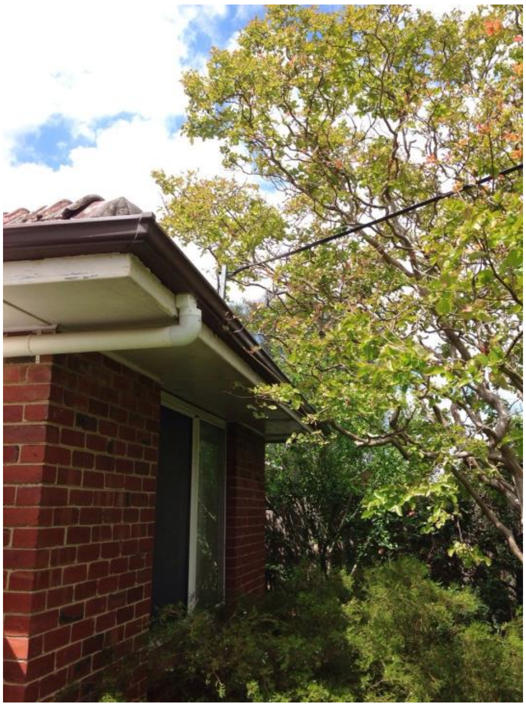

**Figure 3: Brick house with tree overhanging roof catchment area.**

**Figure 4: Polycarbonate tank with direct downpipe inflow and wet charge system. Tank installed on pre-existing paving.**

**Figure 5: Lead flashing used on air vents.**

**Figure 6: Fouling and leaking around overflow mesh. Disconnection indicates tank may have moved.**

Figure 7: Inlet filter full of debris and vegetation.

Figure 9: Fouled mosquito mesh at overflow which indicates high levels of sediment in the tank water.

Figure 8: Rain-head and stormwater switch installed prior to tank inlet.

Figure 10: High-risk set-up. High center of gravity, non-concrete base, pallets and ladder at risk of falling, hose is a tripping hazard.


**Figure 11: Electronic diverter and in-tank sump-pump with filter.**

**Figure 12: Pump with pressure vessel.**

**Figure 13: Pump system with copper piping and dual filters (pump enclosure not visible).**

**Figure 14: Light green water sample indicates high levels of algae.**

**Figure 15: Clear sample indicates high quality water.**

**Figure 16: Light brown sample indicates high levels of tannin.**

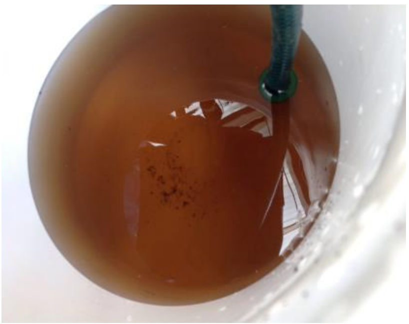

**Figure 17: Dark brown sample indicates high levels of sediment and tannin.**

**Figure 18: Black sample indicates anoxic water, high levels of organic matter in tank.**

**Figure 19: Picture of water in white bucket, light brown colour indicates tannins from leaves.**

# 3. Metering study methodology

The metering of rainwater usage occurs in 21 sites across Melbourne. The study has been undertaking along the lines of the previous study by Umapathi and colleagues (Umapathi et al., 2013, Umapathi et al., 2012). Installation and de-installation of equipment has been undertaken by BMT WBM and REIDenvironmental.

## 3.1. Engagement protocol

The engagement protocol with the participants for this study was reviewed and approved in accordance with CSIRO's Human Research Ethics Policy. Participation consent forms have been developed and used, as are shown in Appendix A. The process for inviting participants into the metering study was according to the following steps:

1. Initial contact to encourage volunteers from the water companies in Melbourne, i.e. in South East Water, City West Water, Yarra Valley Water and Melbourne Water. This allowed us to set up a list of potential participants, with some information about the site characteristics. By this method we managed to get 25 potential participants for the survey.
2. A selection was made of a range of participants to fulfill the following criteria:
    a. As many as possible tanks with internal rainwater usage (up to a maximum of 15 as we also want a control group of tanks where rainwater is only used for external purposes)
    b. An acceptable distribution of sites across the Melbourne geographical area. This is evaluated by means of mapping the sites. The spread that was achieved is shown in Figure 1.
    c. Achieving as close as possible to 7 participants from each water utility area.
3. A list of participants was identified with potential volunteers who were invited into the study by means of email. They were supplied with an information sheet as well as a participation consent form. Volunteers returned the consent forms.
4. Participants were contacted by phone by BMT WBM to organize the installation of equipment.
5. Plumbers arrived on site and inspected the site conditions. In the cases when there was no pump connected to the rainwater tank system, it was deemed that metering was not feasible because the metering equipment require a reasonable amount of pressure in order to be accurate. In this process, a handful of sites were removed from the initial list, and a number of additional participants were included (in order to make up the numbers, one CSIRO staff member was finally invited into the study).

It is acknowledged that because all the participants are staff members at the Melbourne water companies, this is not a sample that is likely to be representative of the community of rainwater tank owners in general. This bias in the sampling schedule was accepted for pragmatic reasons and as it is only a pilot study. However, it is likely that this chosen group of participants have different water use behaviour as well as a different configuration of their rainwater tank systems, in comparison to an "average" selection of Melbourne households.

## 3.2. Metering setup

Flow metering equipment has been installed as per set-ups shown in *Appendix I* by the company BMT WBM[4] according to plumbing regulations, and as per photograph in Figure 21 to Figure 24. Meters/loggers have been installed on pumps as per Figure 22. In a number of sites, depth probes

[4] Organised by Reid Butler (Reid.Butler@bmtwbm.com.au)

have been installed, as per Figure 25. For tank water depth measurement Odyssey capacitance water level probes have been used[5].

Depth probes measuring the water depth in the tank have also been installed in a number of sites.

For metering, Elster V100 20mm PSM-type water flow meters[6] and Ampy EM1000 electricity meters[7] have been used. All water flow meters have a pulse conversion rate of 0.5 L/pulse except for mains water meters which were pre-configured at 5 L/pulse. Depth gauges measure the depth of water at 15 minute intervals. The electricity meters installed generate one pulse per Watt-hour with data recorded in one-minute time steps. The theoretical resolution of the depth gauges is 0.8mm, and measurements in practice have confirmed that an accuracy of +-1mm can be achieved in practice (Matthew Burns, matthew.burns@monash.edu, personal communication, 8th April 2013).

The meters, with the exception of depth meters, are connected to loggers. The loggers are battery powered remote data loggers with four channels to count pulses from the water and electricity meters. These loggers are programmed to collect data at any interval and send the data twice daily via 3G/GPRS or GSM mobile communications to a secure server. The server is called NEON and it communicates with the loggers over internet protocol IP. The server presents the data on a website with graphing and analysis tools. It is hosted by Unidata, the manufacturers of the data loggers.

The Odyssey capacitance water level meters work by measuring the capacitance of the water body (its ability to hold an electric charge). The larger the body of water (i.e. the higher the water level) the higher the capacitance is. Given that this provides a monotonously increasing function (i.e. a function that preserves the order of values, so that for example a higher x value immediately implies a higher y-value), with appropriate calibration, this means that the water level of the tank can be inferred from the measured capacitance of the water.

The data collected by depth meters is stored within the devices themselves. The devices have a capacity of 32,000 readings which means that with 4 readings per hour for a year can be stored within the device. The data will be downloaded after six months.

For other meters, the frequency of logged recordings was 1 minute. Each month the Contractor will conduct a quality assurance check of the datasets and deliver them to CSIRO. The data is in a .csv format. In the first two months, data was transferred fortnightly, then monthly after that. The data was monitored to ensure that poorly functioning or damaged loggers are replaced and any missing data periods are kept to a minimum. In response to this monitoring of performance in different sites, technicians returned to metering sites in August and November 2013.

Data was assessed daily using automated alarms that check that the loggers were providing data. If an alarm was triggered and a problem identified it was investigated by someone within 3 business days. The problem is of course that it is sometimes difficult to know whether meters are genuinely logging zero usage or whether there is something wrong with them.

The batteries that were used were Lithium Thionyl Chloride (LiSOCl2) which should last for at least five years.

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5 http://odysseydatarecording.com/index.php?route=product/product&product_id=50
6 http://www.elstermetering.com/downloads/V100_SML001_Spec_aus_0905.pdf
7 http://www.ampymetering.com.au/products/em1000.html#

Furthermore, at all sites there was an internal fixture audit, during which the tank dimensions were measured. This allows for estimating the actual and active volumes of the rainwater tank systems.

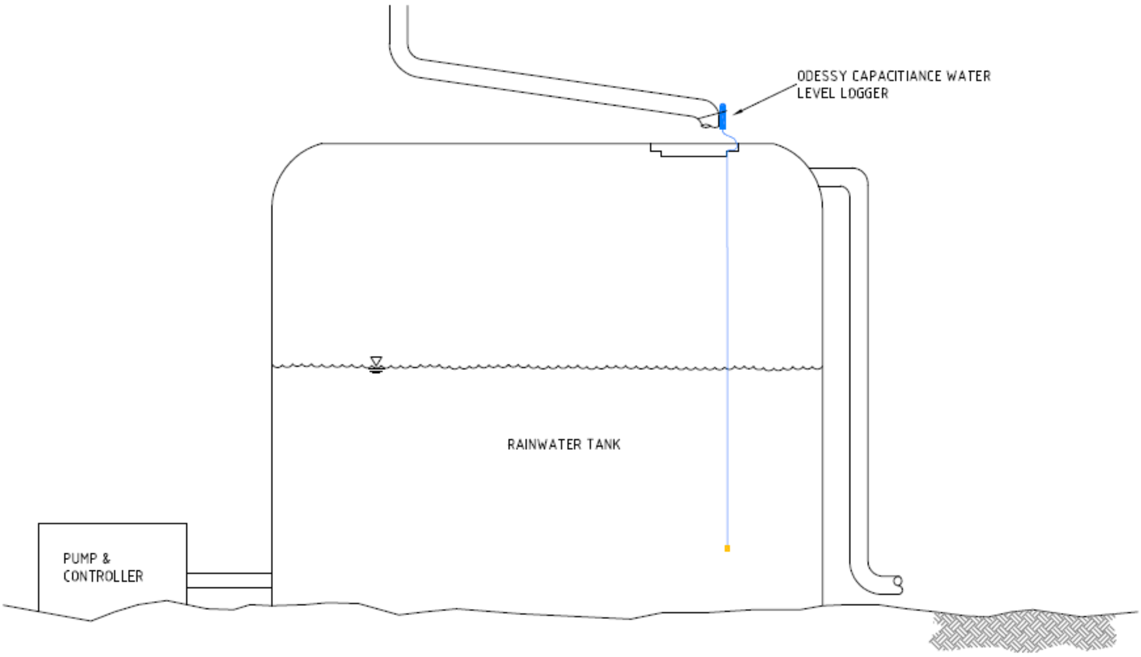



Figure 20: Conceptual diagram showing the installation of depth probes

Figure 21: Equipment installed at a second study site

**Note**: This is a pump and Rainbank (water diverter switch), which determines when the rainwater tank is empty, to source water from the main pipe. The 20mm PSM meter is measuring all water flow out of the tank. The loggers are not in the picture.

**Figure 22: Photo of a pump with meters**

**Note**: This photo of the pump shows the meters on the main inlet and all water out. The logger is inside the grey bag to the right, a bit clouded by the water on the camera lens.

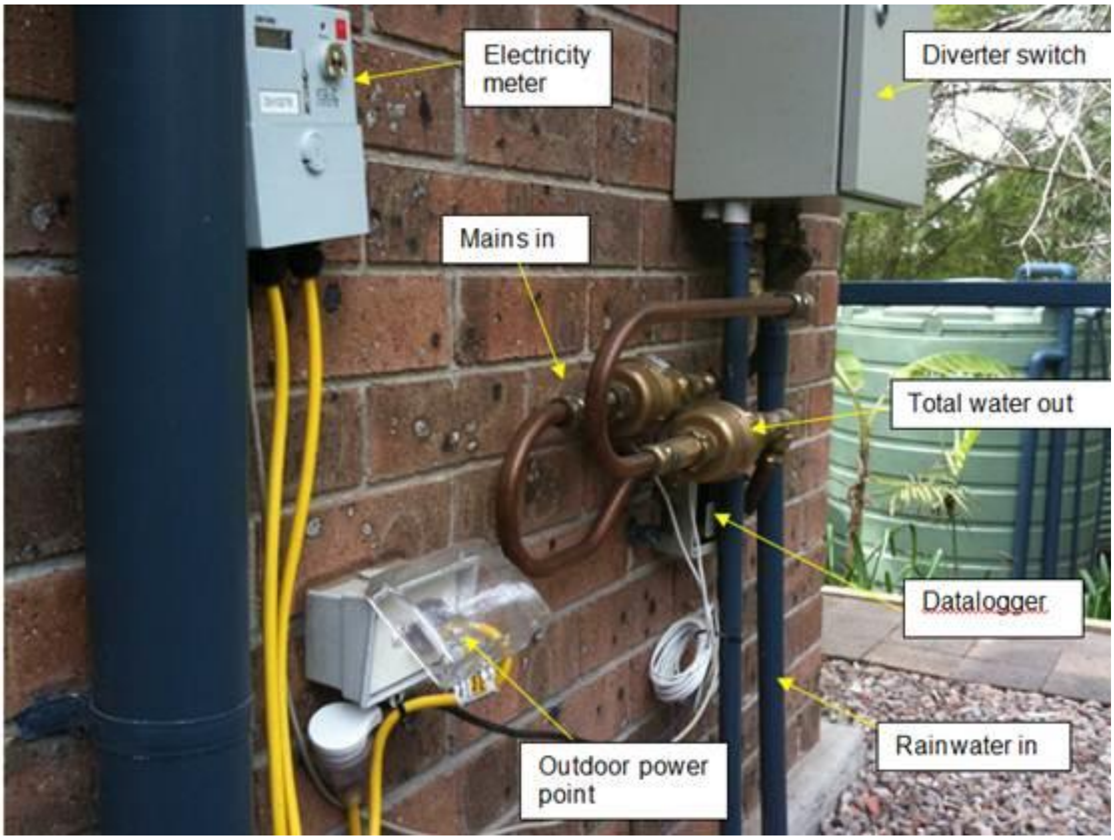



**Figure 23: Setup of flow meters and data loggers in site**

**Figure 24: Flow meter connected to garden tap**

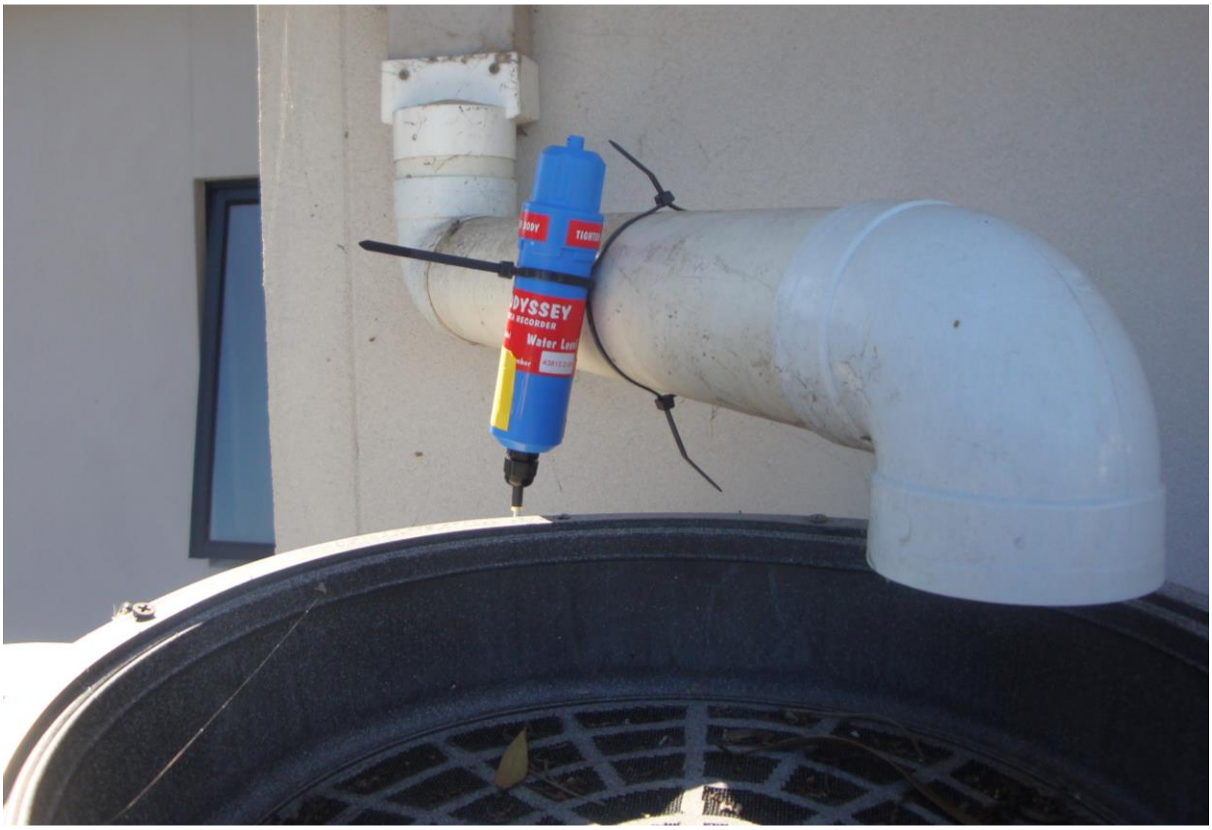


**Figure 25: Depth gauge connected to tank**

### 3.1. Volunteer engagement

Subsequent to the installation process, communication was received of a number of concerns and/or issues with the installation process including:

- One incidence where the plumbers left the gate unlatched and also left a valve open on the tank and the householder returned to an empty tank.
- One incidence where the pump cover no longer fitted over the pump after installations had occurred and the plumbers have subsequently returned to ensure the pump cover fits over the pump. In this case there were also some concerns about the ability to fill a bucket from one of the outdoor taps, but a hose would have to be used to fill the bucket. In this case, the meter monitoring the tap has been removed as it was thought to provide limited benefit but considerable hassle to the home owner.
- Due to the late addition of the depth meters into the study, plumbers had to return to sites after two weeks to install the depth probes and the put in new batteries.

These queries were responded to, and the plumbers have appropriately dealt with these issues and concerns. In light of these concerns a participant feedback survey after installations and inspections has been completed, and one participant raised some concerns regarding the inconvenience of attending at various times when the equipment was installed and uninstalled and when data was downloaded. Another participant was concerned about the fact that information about faulty equipment was only provided at the end of the study. Participants were also provided with a recommended maintenance schedule for their tanks (see Appendix E).

## 4. Condition survey results

The survey of 417 household rainwater tank systems includes tank condition inspections and questionnaires and has been undertaken across the Metropolitan area as defined by the operational areas of the three major Melbourne water retailers (City West Water, Yarra Valley Water and South East Water). Geographically, the survey and inspections have been undertaken in a wide area, as shown in Figure 26. The distribution of households for rainwater tank condition survey across the three retailers is as per Table 2. Nearly a third of inspections have been undertaken in each of the three retail areas; however there is a slight bias towards Yarra Valley Water at the expense of South East Water. This was primarily due to the influx of volunteering participants from the YVW and CWW areas late in the survey which was primarily driven by word of mouth.

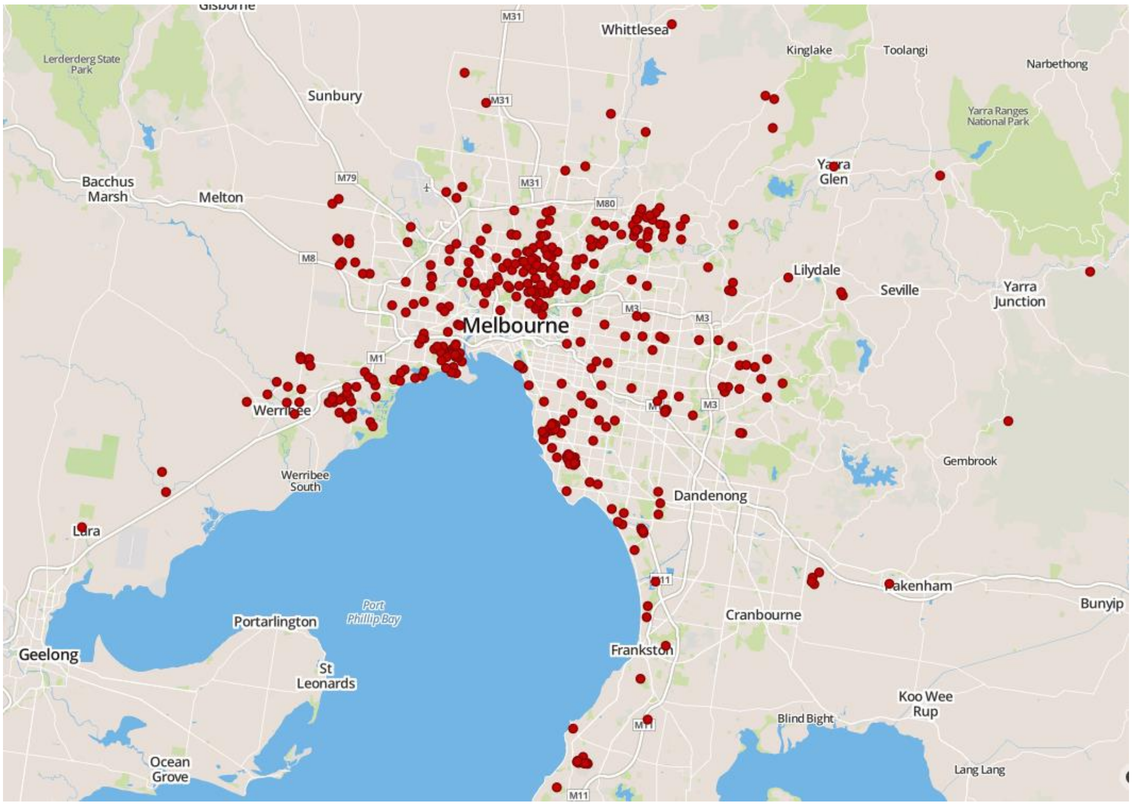



**Figure 26: Distribution of tank inspections across the Melbourne metropolitan region***

***Note**: There are areas of Melbourne where recycled water supplied to households (purple pipe), and in these areas rainwater tanks are rare. These areas are particularly common in the South East of Melbourne around Dandenong, Cranbourne and Pakenham in which areas fewer than ideal rainwater tanks have been inspected. Attempts were made to inspect tanks in these areas based on distribution of pamphlets and door-knocking but in these areas this yielded relatively poor results.

**Table 2: Distribution of inspected tanks per Water Company distribution area**

| Water company | Number of participants | Percentage of sample |
|---|---|---|
| City West Water | 139 | 33% |
| South East Water | 116 | 28% |
| Yarra Valley Water | 162 | 39% |
| **Total** | **417** | **100%** |

## 4.1. Identified faults

The key purpose of the condition survey of rainwater tanks was to get an idea of the rates of errors that occur within the urban tank population in Melbourne, and whether these types of faults have an impact on health risks to the public or water savings potential of tanks. The types of issues that are explored within inspections are described in section 2.3.

## 4.2. Installation incentives

This study was limited in scope to residential households. Household tanks are categorized as ***regulated*** (i.e. installed in response to 5-star regulation of new homes constructed since July 2005), ***rebated*** (i.e. when provided with a rebate as an incentive for installing a tank), or ***independent*** (i.e. installed neither in response to regulation nor rebate incentives). However, some households surveyed could not clearly identify if their tanks were installed under rebated or regulated category. The split between these categories is shown in Table 3 with 83 "regulated" tanks inspected, 154 "rebated" tanks inspected, and 177 tanks that are neither regulated or rebated (i.e. "independent"). It is also worth noting that a number of inspected household tank systems do not neatly fall into these three categories.

**Table 3: Number of sites that are regulated and/or rebated**

| | Rebated | Unknown whether rebated | Not rebated | Total | Percentage |
|---|---|---|---|---|---|
| **Regulated** | 23** | 4 | 56 | **83** | 20% |
| **Unknown whether regulated** | 4 | 2 | 5 | 11 | 3% |
| **Not regulated** | 127 | 19 | **177*** | 323 | 77% |
| **Total** | **154** | 25 | 238 | 417 | 100% |
| **Percentage** | 37% | 6% | 57% | 100% | |

***Note**: The sites categorized as "independent" are those that are neither rebated nor regulated. This category represents 42% of the sample.

****Note**: It is noted that in theory there should be no tanks that fit both the rebated category and the regulated category simultaneously; yet 23 sites have been identified by the householders as such.

A key factor to consider is the age of the inspected tank, commonly believed to impact on the condition of tanks. The age of tank systems can be deducted from the age of installation. The distribution of installation years for inspected tanks is shown in Table 4.

It is thought that most of the tanks in Melbourne were installed in response to prolonged drought conditions, with the peak of the recent drought occurring in 2006-2007. This aligns with a significant proportion of inspected tank systems being installed in the peak time period 2007-2010 (62% of inspected tanks). Some of the inspected sites have multiple tanks that have been inspected, and the distribution of tanks per site is shown in Table 5. The total number of tanks inspected, 734, is thus much higher than the number of sites visited, 417. This means *there is an average of 1.8 tanks per tank system site in our sample*.

Table 4: Installation years of inspected tanks

| Installation year | Number of tanks inspected | Percentage of tanks inspected | Percentage regulated | Percentage rebated |
|---|---|---|---|---|
| Pre-2000 | 20 | 3% | 5% | 15%** |
| 2000 | 8 | 1% | 0% | 63%** |
| 2001 | 3 | 0% | 0% | 0% |
| 2002 | 14 | 2% | 0% | 0% |
| 2003 | 10 | 1% | 10% | 40% |
| 2004 | 15 | 2% | 0% | 20% |
| 2005 | 13 | 2% | 15% | 38% |
| 2006 | 40 | 5% | 23% | 30% |
| 2007 | 81 | 11% | 6% | 49% |
| 2008 | 145 | 20% | 14% | 59% |
| 2009 | 115 | 16% | 25% | 49% |
| 2010 | 111 | 15% | 28% | 54% |
| 2011 | 57 | 8% | 42% | 30% |
| 2012 | 30 | 4% | 37% | 30% |
| 2013 | 9 | 1% | 11% | 0% |
| 2014 | 2 | 0% | 0% | 50% |
| No data | 61 | 8% | 10% | 11% |
| Total | 734* | 100% | N/A | N/A |

***Note**: Some sites have multiple tanks and therefore the number of tanks is greater than the number of inspected sites.

****Note**: As far as the authors are aware, rebates for rainwater tanks were not available 2000 or earlier but were introduced in 2003. Therefore, it is unclear why so many of these respondents claim to have been getting a rebate.

Table 5: Number of tanks per site*

| Number of tanks per site | Number of inspected sites | Percentage of sites | Number of inspected tanks |
|---|---|---|---|
| 1 | 239 | 57% | 239 |
| 2 | 104 | 25% | 208 |
| 3 | 43 | 10% | 129 |
| 4 | 17 | 4% | 68 |
| >4 | 14 | 3% | 90 |
| **Total** | 417 | 100% | 734 |

***Note**: There is unfortunately no information on whether tanks are inter-connected.

## 4.3. System characteristics

A number of key characteristics of tanks were explored in the condition and household survey. Figure 27 shows the distribution of tank types. The majority of the tanks were round, 51%, or slimline tanks, 41%. Other tank types (bladder, modular, underground and other) constituted only 7% of the sample. In terms of materials, tanks were predominantly manufactured of polyethylene (76%) as shown in Figure 28. Other materials metal, i.e. Colorbond and corrugated galvanized iron comprised 16%, and very few were made of other materials (PVC, concrete, steel, and fiberglass) i.e. only 7% of the sample. Only 1% of tank materials could not be identified by the surveyor.

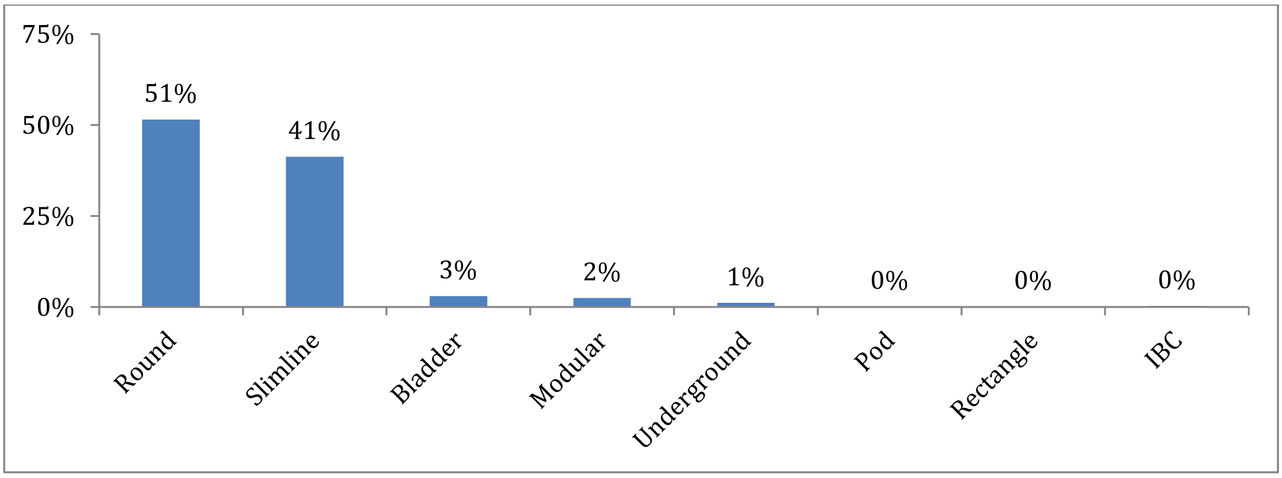



Figure 27: Distribution of tank types

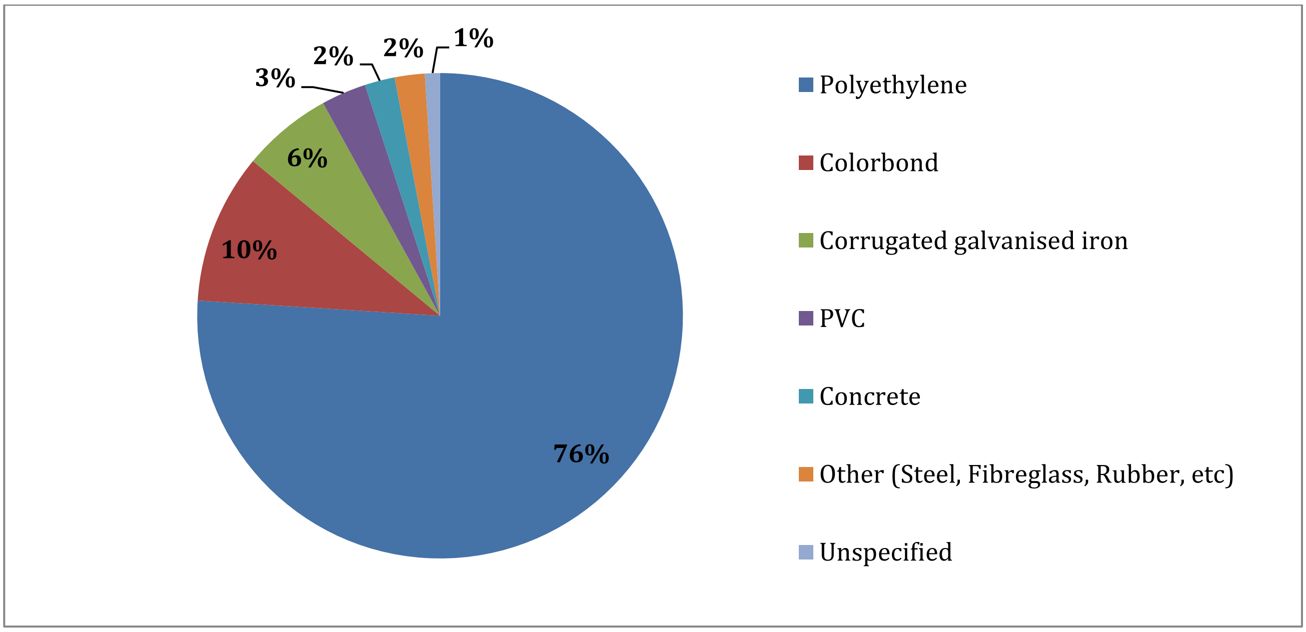



**Figure 28: Distribution of tank materials**

Figure 29 shows the other tank system components:

- Lead flashing was installed in 39% of roofs, however in 16% of dwellings the surveyor could not determine if it was present. Lead flashing is a source of lead in sediment in tanks and needs to be monitored if water is used for drinking purposes;
- Overall, screen guards and mosquito meshing were the main ancillaries installed with tanks and observed in respectively 92% and 91% of tanks. However, it is a concern in terms of the risk of arbovirus that 8% of tanks had no mosquito mesh;
- Signage which is a required feature for any dwelling using rainwater is not strongly adhered to and only 26% of the dwellings had proper signs;
- Leaf guards and first flush devices, which reduce the ingress of leaf matter and sediment into tanks, and pressure vessels, which assist in reducing the deterioration of pumps, were uncommon and only installed in 8% of the sample.
- Automatic mains water diverters were installed in 25% of the sample.

The roof area connected to the rainwater system is a key parameter for estimating the rainwater harvesting potential. Whilst the connected roof area was not evaluated during inspections, the number of downpipes out of the total connected to the rainwater tank can serve as an indicator of the percentage of total roof area adopted for harvesting. The number of downpipes connected to the tanks is shown in Table 6. Approximately 57.1% of tanks were connected to two or less downpipes, 20.4% were connected to three to four downpipes, 13% were connected to five to seven downpipes and 10.1% were connected to 6 to 10 downpipes, whilst 5.5% were undetermined.

The percentage of the roof area that was connected was also estimated by the surveyor and the results of these estimations are shown in Figure 30. As can be seen, only in about a third of cases, more than 60% of the roof has been connected to a rainwater tank. In addition to the rainfall characteristics of the area, the connected roof area and how the collected rainwater is used, the storage volume of a rainwater tank influence the potential for water savings for a household rainwater tank system. The distribution of sizes for tanks is shown in Table 7. The most common tanks volumes were 1-2kL and 2-

3kL, representing 20% and 29% of the sample, followed by 3-4 kL and 4-5kL for 10% and 13% of the sample, respectively. Tanks of smaller and larger volumes represented 13% and 11% of the sample, however the last figure also included a number of dwellings with multiple tanks totaling 10 to >20kL volume (6% of total sample).

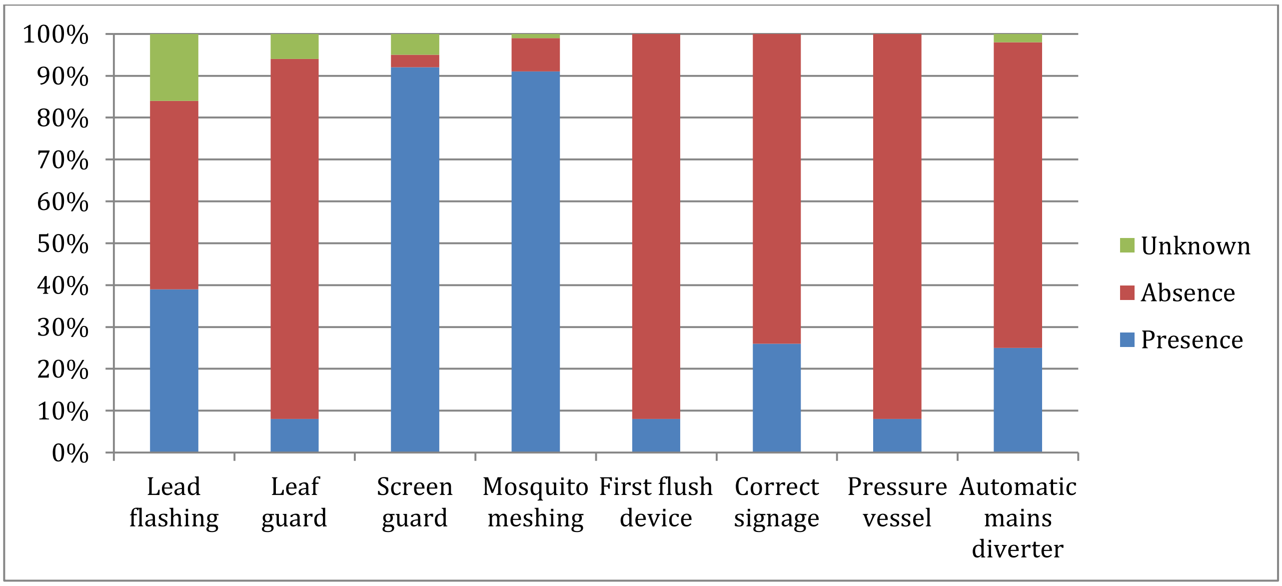



**Figure 29: Presence or absence of devices/features in tank systems**

**Table 6: Number of downpipes connected to tank**

| Number of downpipes | Number of sites | Percentage |
|---|---|---|
| 1 | 130 | 31.2% |
| 2 | 108 | 25.9% |
| 3 | 56 | 13.4% |
| 4 | 29 | 7.0% |
| 5 | 29 | 7.0% |
| 6 | 12 | 2.9% |
| 7 | 13 | 3.1% |
| 8 | 11 | 2.6% |
| 9 | 2 | 0.5% |
| 10 | 4 | 1.0% |
| Unknown | 23 | 5.5% |

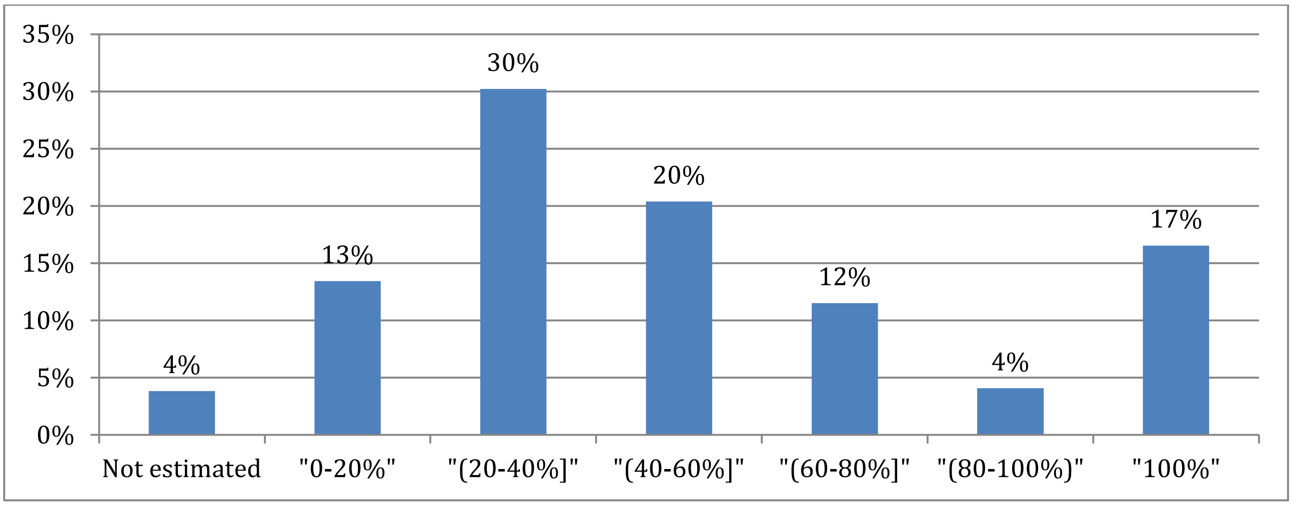



**Figure 30: Estimation of the percentage of the roof area connected to rainwater tank(s)**

**Table 7: Distribution of tank sizes per tank***

| Volume range (kL) | Number of tanks | Percentage of tanks (total) |
|---|---|---|
| <0.5 | 25 | 3% |
| (0.5-1] | 77 | 10% |
| (1-2] | 150 | 20% |
| (2-3] | 216 | 29% |
| (3-4] | 73 | 10% |
| (4-5] | 94 | 13% |
| (5-6] | 11 | 1% |
| (6-7] | 8 | 1% |
| (7-8] | 9 | 1% |
| (8-9] | 10 | 1% |
| (9-10] | 16 | 2% |
| (10-20] | 24 | 3% |
| >20 | 20 | 3% |
| no data | 1 | 0% |
| **Total** | **734** | **100%** |

***Note**: The average tank volume was 4.3 kL and the median tank volume 2.6 kL.

## 4.4. Rainwater end uses

The way that householders use the rainwater is important for determining the potential water savings of rainwater tanks for a household. In particular, it is important to know whether rainwater collection systems are plumbed into the house so that collected water can be used year-around for indoor purposes. The proportions of household rainwater tank systems that supply water inside the house are shown in Table 8. Fifty-one percent of tanks had indoor connections, whilst the remainder only supplied outdoor uses.

**Table 8: Sites with indoor connections**

| Connection indoors | Number of sites | Percentage of sites |
|---|---|---|
| Indoor connection | 214 | 51% |
| No indoor connection | 203 | 49% |
| **Total** | **417** | **100%** |

It was also investigated if the internally plumbed rainwater tank installed under rebate program or in order to comply with building regulations. As per Figure 31, this shows up in the data: 94%, 68% and 32% of regulated, rebated and independent tanks were connected indoors. *However whilst it ought to be expected that all regulated and rebated sites are connected indoors for toilets and other purposes; the reality is that some householders may opt out of such an arrangement, or they may be unaware that water is used for indoor purposes*. It is noted that this data is based on householder survey responses rather than actual inspections households for indoor tank connections.

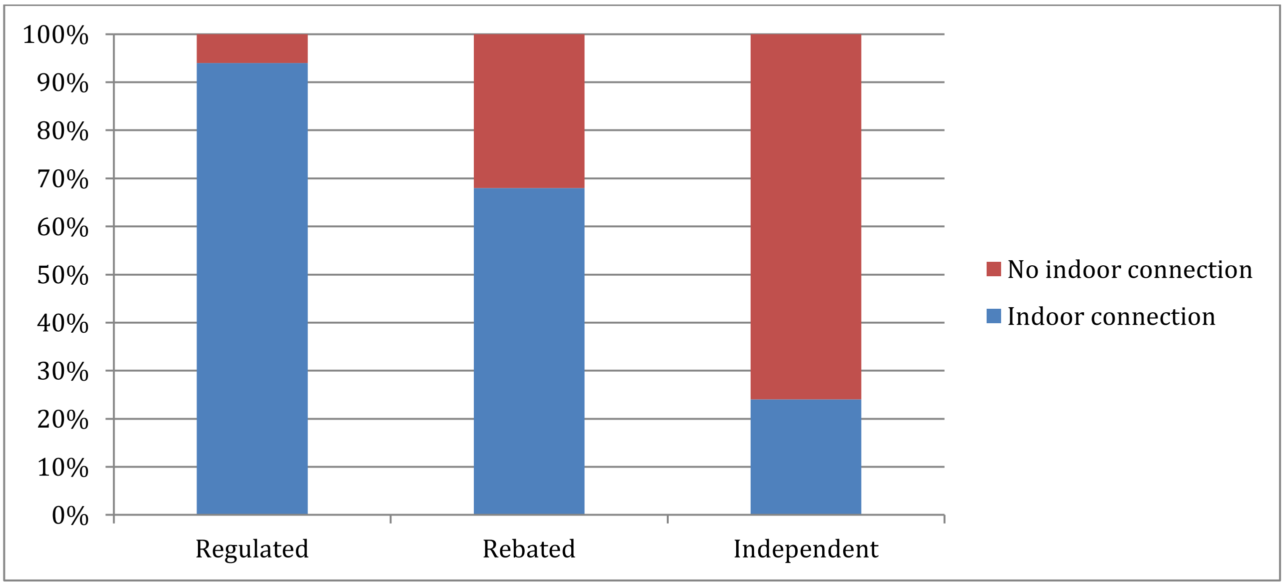



**Figure 31: Indoor connections among tank categories**

For the households where the rainwater is being supplied into the house, there could be a range of indoor water uses, as per Table 9. Toilet cistern supply was the main end use, 94% of dwellings. Washing machine and laundry were supply were observed for respectively 50% and 28% of the sample. Higher risk exposure from supply of hot water and shower, and, cooking and drinking, were adopted in 14% and 9% of dwellings, respectively.

**Table 9: Indoor uses at sites with an indoor connection**

| Types of connections | Number of sites* | Percentage of sites |
|---|---|---|
| Toilet(s) | 188 | 94% |
| Washing machine | 100 | 50% |
| Laundry tap | 56 | 28% |
| Hot water & shower | 28 | 14% |
| Drinking & cooking | 18 | 9% |

*__Note__: A site can have rainwater connected indoors for more than one uses. For example, it may be connected to one or more toilets, as well as laundry and even the hot water systems. This is the reason that the total number of sites in this table adds up to significantly more than the total number of sites (households) inspected.

As noted in this table, the total number of sites is greater than the number of sites inspected, because a site may have multiple uses for the collected rainwater. In order to provide a normalized view of the network, another perspective on the data is therefore provided that shows three distinct levels of rainwater use: 1) outdoor only, 2) outdoor and toilets, and 3) outdoor, toilets and other indoor uses. Using this classification, Table 10 and Figure 32 shows the distribution of rainwater usage patterns across the inspected tank sites. Approximately half of the tanks inspected were used solely for outdoor purposes and half for both indoor and outdoor use.

**Table 10: Usage pattern distribution among participants**

| Usage pattern | Number of sites | Percentages |
|---|---|---|
| **The Gardener**: rainwater is used for outdoor purposes only | 190 | 47% |
| **The Utilitarian**: rainwater used for outdoor purposes and for toilets | 92 | 23% |
| **The Enthusiast**: rainwater used for outdoor purposes and other indoor uses and/or toilets | 107 | 26% |
| **The Rejecters:** rainwater is not used for any purposes | 4 | 1% |
| **Unknown:** Participant has either not divulged the information, or the survey is yet to be completed | 11 | 3% |
| **Total** | 404 | 100% |

**Note**: The terms gardener, utilitarian, rejecters and enthusiast to denote different usage patterns has no theoretical foundation other than our emerging understanding of people's motivations for installing and using tanks. The gardeners are primarily concerned about their garden, the utilitarians are primarily concerned about meeting regulation and have a set up that is thought to maximize the return on investment, and the enthusiasts are generally very positive about rainwater tanks and utilise the water for as many different purposes as possible.

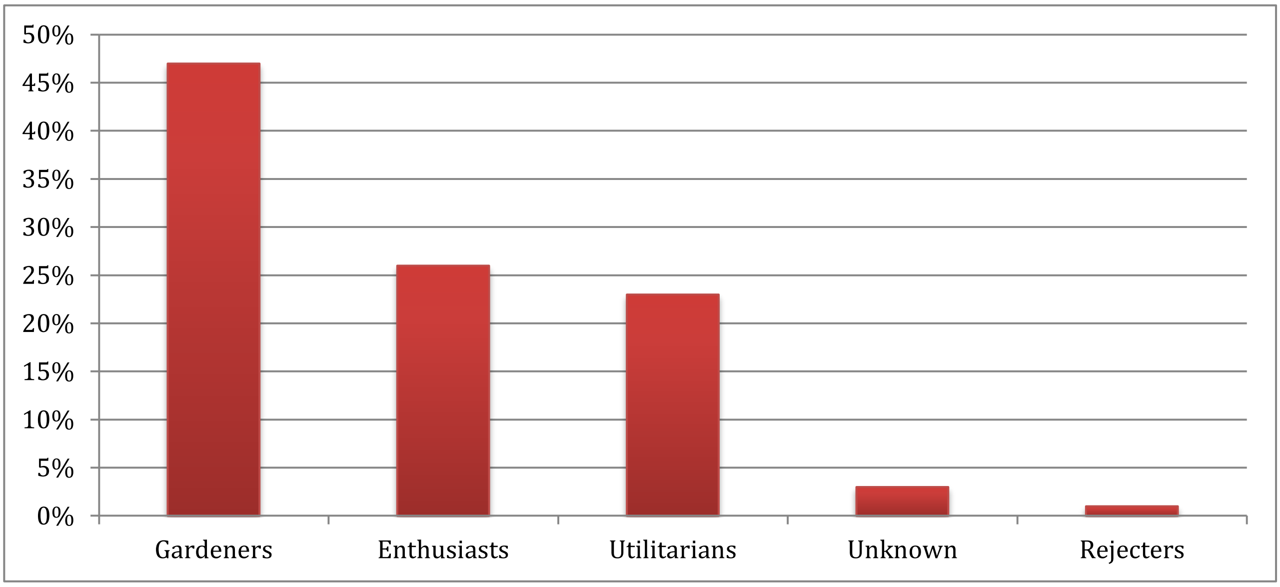



**Figure 32: Distribution of tank use patterns**

## 4.5. General concerns about tank systems

The condition of the rainwater system provides an indication of the potential life of the system and its performance, as systems in poor condition may lead to faults of early failure of the system. A majority of the tanks, 98%, were in good or fair condition (Table 11) and showed no evidence of plastic degradation. But only 49% of the pipe work was properly connected to the tanks and were in a good or fair condition, curiously 10% had no pipe work connected and 40% could not be inspected (thus provides only the partial information of the rainwater tank system plumbing).

**Table 11: General conditions of tank systems**

| Condition grading | Overall condition of rainwater tank* | Overall condition of rainwater tank (%) | Condition of pipe work** | Condition of pipe work (%) |
|---|---|---|---|---|
| Good | 349 | 86 | 177 | 42 |
| Fair | 50 | 12 | 28 | 7 |
| Poor | 6 | 1 | 1 | 0 |
| Not connected | N/A | N/A | 43 | 10 |
| Unknown | 0 | 0 | 168 | 40 |

*__Note__: For the *Overall Tank Condition,* tanks was categorized as Good, Fair or Poor based on any obvious characteristics that would reduce the tanks capacity to provide clean water safely such as damage to the tank infrastructure, holes, rust, lean etc. Minor characteristics would result in a 'fair' rating, with the more significant characteristics resulting in poor, and the absence of any such characteristics resulting in a 'good' rating.

**__Note__: For this question, the definitions are Good = Clean & no signs of corrosion/damage; Fair = Minor signs of corrosion/damage; and Poor = Extensive corrosion/damage.

The tank overflow was generally in good condition and properly connected in 87% of the systems, 15% had a slight leak and 7% were in poor condition and 1% had no overflow (shown in Table 12). Taps generally had no leaks in 77% of tanks and leaks were detected in only 9% of cases (Table 13). In addition, correct signage was only adopted in 26% of dwellings, with the majority displaying no signage (Table 13).

**Table 12: Effectiveness of overflow**

| Effectiveness of overflow | Number of sites | Percentage of sites |
|---|---|---|
| Good condition/ functionality | 363 | 87% |
| Poor condition / functionality | 29 | 7% |
| No overflow | 5 | 1% |
| Slight leak | 62 | 15% |
| Unknown | 11 | 3% |

**Table 13: Further general problems with tanks systems**

| Presence of issue | Leaking taps | Leaking taps (%) | Evidence of plastic corrosion | Evidence of plastic corrosion (%) | Correct signage of rainwater | Correct signage of rainwater (%) |
|---|---|---|---|---|---|---|
| Yes | 36 | 9 | 8 | 2 | 107 | 26 |
| No | 320 | 77 | 404 | 97 | 307 | 74 |
| Unknown | 61 | 15 | 5 | 1 | 3 | 1 |

## 4.6. Pumps and mains diverters

The condition and operation of pumps and diverters are essential to ensure that a dwelling is able to use rainwater at satisfactory service levels. Pumps were installed in 86% of dwellings, whilst 14% of dwellings adopted gravity-based systems. Among dwellings with pumps 90% were operational, 5% we not functioning and 4% could not be determined as the householder was not home at the time of inspection (Table 14). Of the tanks that were present, approximately 90% were operational at the time of installation (Table 15). Figure 33 summarizes this information to show the distribution of situations in different sites. Sixty-three percent of installations still had the original pump that was installed with the tank, however 13% experienced pump failure and had either purchased a new pump, had it repaired or removed altogether (Table 16). Among the tanks with pumps, 77% were tested for abnormal noises and 80% for leaks, the remainder could not be tested because of lack of water in the tank or because the pumps were not working (Table 17). Among that majority were in good condition: only 3% had abnormal noises, however 18% leaked. Approximately 21% had no pump enclosure, 31% could not be determined or examined due to access restrictions, however the remaining 46% were in good or fair condition and only 2% were in poor condition (Table 18). However, a greater concern was that among the 54 dwellings with tank systems with electronic diverters, at least 52% had failed at least once and 35% were not operational at the time of inspection (Table 19). Figure 34 summarizes the information about diverters.

**Table 14: Presence of pumps**

| Presence of pump or not | Presence of pump (number of sites) | Presence of pumps (%) |
|---|---|---|
| A pump is present | 359 | 86 |
| No pump is present | 58 | 14 |
| Unknown | 0 | 0 |

***Note**: It was not always possible to test whether a pump was functional; for example if there was no water in the tank.

**Table 15: Functionality of pumps**

| Functionality of pump | Pump operational for the 359 sites with pumps | Pumps operational when present (%) |
|---|---|---|
| The pump is operational | 324 | 90.3 |
| The pump is not operational | 19 | 5.3 |
| Unknown | 16* | 4.4 |

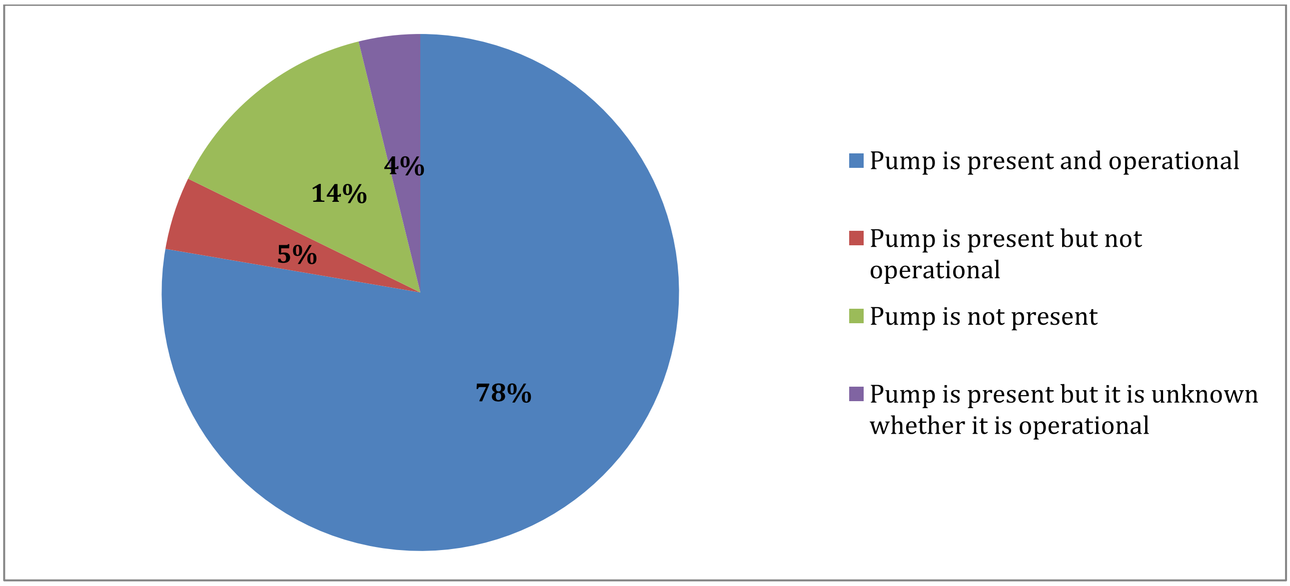



**Figure 33: Proportions of tank systems with presence and condition of pumps**

Table 16: Pump history*

| Situation | Pump history* – number of sites | Pump history* - percentages (%) |
|---|---|---|
| Original unit still present | 192 | 63 |
| Unit has been repaired | 4 | 1 |
| Unit has been replaced | 33 | 11 |
| There is no pump present | 43 | 14 |
| The pump is not operational | 14 | 5 |
| The pump has been removed | 4 | 1 |
| Unknown | 15 | 5 |

***Note**: This inspection item was added only in the second phase of the condition inspections – and thus was only explored for 305 sites in total.

Table 17: Pump condition

| Pump issue response | Abnormal noises | Abnormal noises (%) | Leaks from pump | Leaks from pump (%) |
|---|---|---|---|---|
| Presence of pump issue (abnormal noise, or leaks) | 13 | 3 | 73 | 18 |
| Absence of pump issue (abnormal noise or leaks) | 307 | 74 | 259 | 62 |
| Unknown | 97** | 23 | 85* | 20 |

***Note**: When there is no water in the tank, it is not possible to check for leaks from the pump.

****Note**: To check for abnormal pump noises, the pump needs to be operational and there needs to be water in the tank.

Table 18: Pump enclosure condition

| Pump enclosure condition | Pump enclosure condition | Pump enclosure condition (%) |
|---|---|---|
| Good | 155 | 37 |
| Fair | 38 | 9 |
| Located beneath decking /home | 29 | 7 |
| Poor | 9 | 2 |
| Not present | 87 | 21 |
| Unknown | 99 | 24 |
| Total | 417 | 100 |

Table 19: Mains diverters

| Type of diverter | Number of sites | Number of these with failure history | Number of these currently broken | Failure rate | Currently non-operational |
|---|---|---|---|---|---|
| Manual | 27 | 0 | 0 | 0% | 0% |
| Electronic | 54 | 28 | 19 | 52% | 35% |
| None | 122 | N/A | N/A | N/A | N/A |
| Total | 203 | N/A | N/A | N/A | N/A |

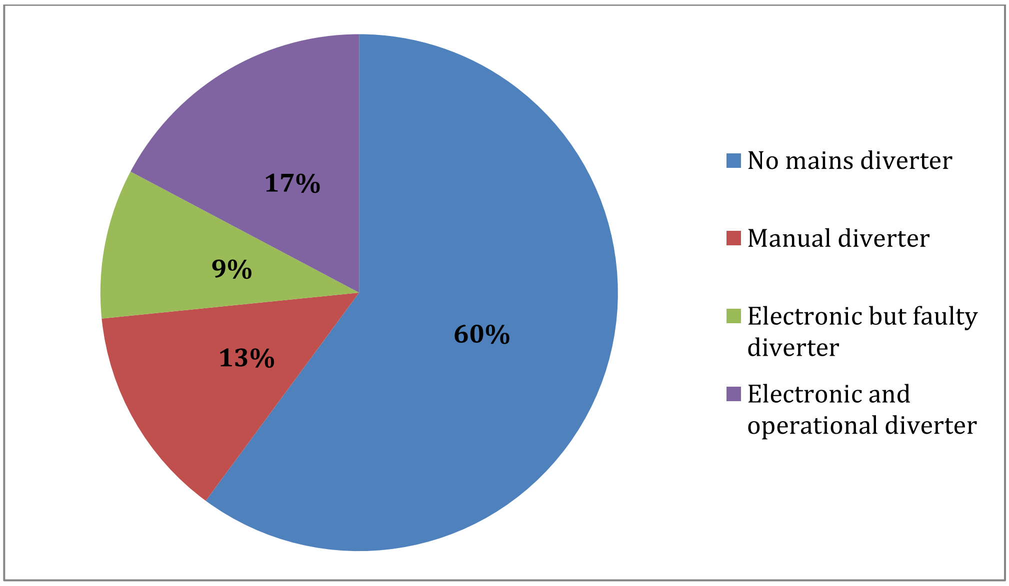



**Figure 34: Summary of diverter information - percentages of diverter types and functionality**

## 4.7. Mosquitoes and insects

Breeding of mosquitoes in tanks is associated with the potential for mosquito entry/exit into the tank system. Whilst Victoria's climate carries a low risk for the proliferation of mosquito related diseases, such as dengue fever; however with climate warming there could be potential for greater risks associated with migration of those species into the future. Mosquito meshing located at the inlet and outlet of the tanks was examined in 417 and 204 tanks respectively. Meshing at the tank inlet was present in 91.1% of the tanks, absent in 7.9% of tanks and could not be examined in 1.4% of tanks. Meshing at the outlet was present in 82.8% of tanks, absent in 15.2% and could not be examined in 2% of tanks. Approximately, 11.3% were in a condition that would allow vermin or insects to enter the tank, 51% would bar entry and 37.7% could not be verified.

**Table 20: Condition of mosquito meshing**

| Response to question | Is there a mosquito meshing fitted to the tank? | Is there a possibility for mosquitoes to enter or exit tank through any meshing? | Is there an insect screen on the overflow pipe?* | Is there a possibility of insects or vermin to enter tank via the overflow pipe?* |
|---|---|---|---|---|
| Yes | 17 (fine mesh)<br>361 (standard screen mesh) | 100 | 169 | 23 |
| No | 33 | 300 | 31 | 104 |
| Unknown | 6 | 17 | 4 | 77 |
| Total | 417 | 417 | 204 | 204 |

***Note**: The condition of mosquito meshing on overflow pipes was verified for 204 tanks. Mosquito meshing on inlet to tank was verified for 417 tanks.

## 4.8. Water quality related parameters

Among tank owners, 50% used the water for washing machine supply and 98% for toilet supply (Table 9), and thus would value the rainwater aesthetics. The concentration of sediment in rainwater was low, medium and high for 64%, 17% and 8% of tanks, respectively (Table 22). In addition, 57% of tanks had discolored water (Table 23) and 19% had odorous water (Table 21). Approximately 14% and 9% of tank owners use the rainwater for bathing and cooking/drinking (Table 9), and hence water quality and health risk mitigation would be important for those end uses. Mosquito larvae were detected in 12.5% of tanks. In addition, 39% of dwellings had lead flashing in their roofs (Table 23 and Table 13), which can cause lead contamination of rainwater. The presence or absence of various water quality issues are summarized in Figure 35.

**Table 21: Rainwater quality**

| Water quality issue | Odour of water | Mosquito larvae in water or mosquito adults present | Lead flashing on roof |
|---|---|---|---|
| Presence of condition (odour of water, mosquito larvae in water or lead flashing on the roof) | 81 | 38 | 164 |
| Absence of condition (odour of water, mosquito larvae in water or lead flashing on the roof) | 314 | 267 | 186 |
| Unknown | 22 | 3 | 67 |
| Total | 417 | 305* | 417 |

*__Note__: The check for mosquito larvae in the water was only added in the second and third round of inspections.

**Table 22: Concentration of sedimentation in tanks**

| Sedimentation level | Concentration of sedimentation | Concentration of sedimentation (%) |
|---|---|---|
| High | 18 | 6 |
| Medium | 52 | 17 |
| Low | 155 | 51 |
| None | 41 | 13 |
| Unknown | 39 | 13 |
| Total | 305 | 100 |

Table 23: Colour of sampled water

| Colour category | Number of sites | Percentage of sites (%) |
|---|---|---|
| Clear | 158 | 38 |
| Light green | 98 | 24 |
| Light brown | 78 | 19 |
| Dark green | 5 | 1 |
| Dark brown | 25 | 6 |
| Brown and green | 30 | 7 |
| No sample | 23 | 6 |
| Total | 417 | 100 |

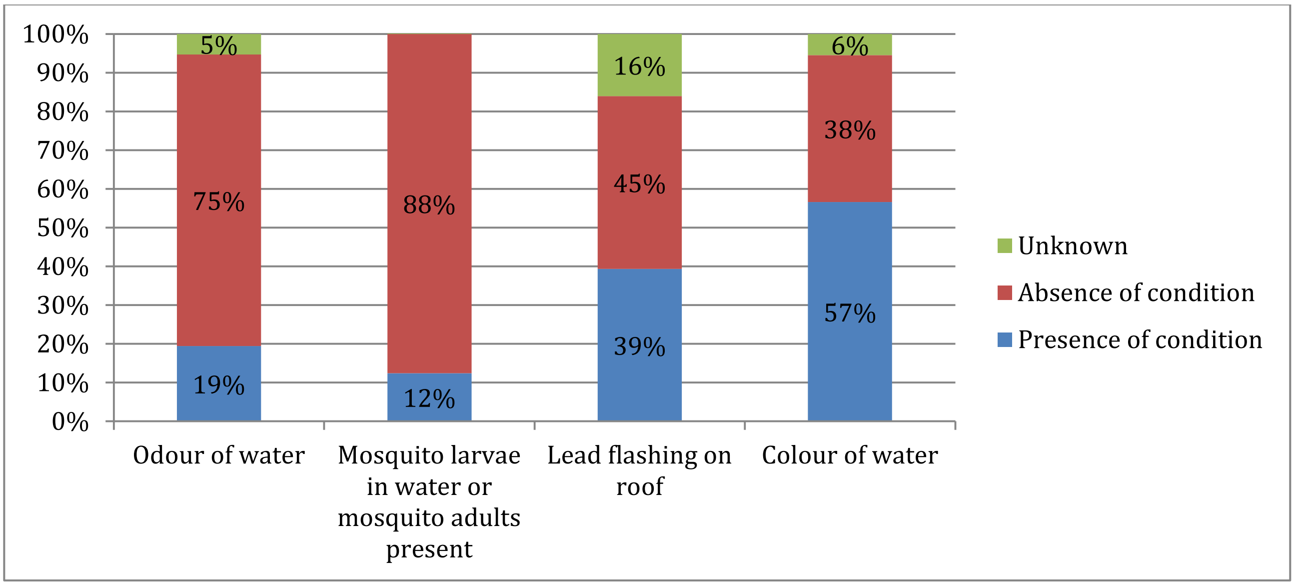



Figure 35: Summary info on water quality issues

## 4.9. Gutters and first flush devices

Debris in the roof and gutters, such as leaf matter, pollution residues and other blown sediments, and faecal matter from birds, lizards or small mammals (e.g. possums) could be washed into rainwater tanks contributing to sediment accumulation, colour (from humic matter decomposition) and or pathogens. In addition, excess debris in gutters can also decrease the harvesting efficiency of rainwater harvesting through reduction of the hydraulic capacity of the gutter during rain events. Trees provide habitat for fauna and close proximity or overhanging branches allow mammals, such as possums and lizards to gain access to the roof, besides contributing to dead leaf matter. Approximately 28% of dwellings had trees overhanging the roof, 33% were located within one to five meters from the roof, whilst 32% had no trees or had trees further than 5m from the roof (Table 24). The reason for the installation of first flush devices and leaf guards is that they are believed to reduce sediments, debris and leaf matter entry into a tank and leaf guards are thought to keeps gutters relatively free from obstructions thus increasing the rainwater harvesting potential. However, only 8.4% and 9.8% of dwellings installed first flush diverters and leaf guards on their systems, respectively (Table 25). Among those 49% of first flush devices were in good condition, but 51% were blocked, which indicates lack of maintenance and would impair their performance in a rain event (Table 26 and Table 27). In 66% of dwellings there were minimal volumes of debris in the gutters, whilst 19% and 12% had gutters that were respectively half or completely filled with debris (Figure 36). Fecal matter in gutters was observed in only 8.4% of dwellings. However, fecal matter presence depends on when it has been deposited and if any flushing had occurred prior to the inspection.

**Table 24: Proximity of trees**

| Proximity of trees | Number of sites | Percentage of sites (%) |
|---|---|---|
| No trees | 82 | 20 |
| Within 5-10 meters | 51 | 12 |
| Within 1-5 meters | 139 | 33 |
| Over gutter / house | 117 | 28 |
| Unknown | 28 | 7 |

**Table 25: Sediment prevention**

| Device issue | First flush device | Leaf guards |
|---|---|---|
| Presence of device (first flush device or leaf guards) | 35 | 39 |
| Absence of condition (first flush device or leaf guards) | 382 | 359 |
| Unknown | 0 | 19 |

**Table 26: Presence of faecal matter in gutters**

| Faecal matter in gutters – situation | Number of sites |
|---|---|
| Presence of faecal matter in gutters | 34 |
| Absence of faecal matter in gutters | 370 |
| Unknown | 13 |

Table 27: Condition of gutters and first flush

| Condition of gutters / first flush device | Integrity of gutter (no. sites) | Integrity of gutters (%) | Condition of first flush device when present (no. sites) | Condition of first flush device when present (%) |
|---|---|---|---|---|
| Good | 383 | 92 | 14 | 40 |
| Average | 21 | 5 | 3 | 9 |
| Poor, i.e. blocked | 10 | 2 | 18 | 51 |
| Unknown | 3 | 1 | 0 | 0 |

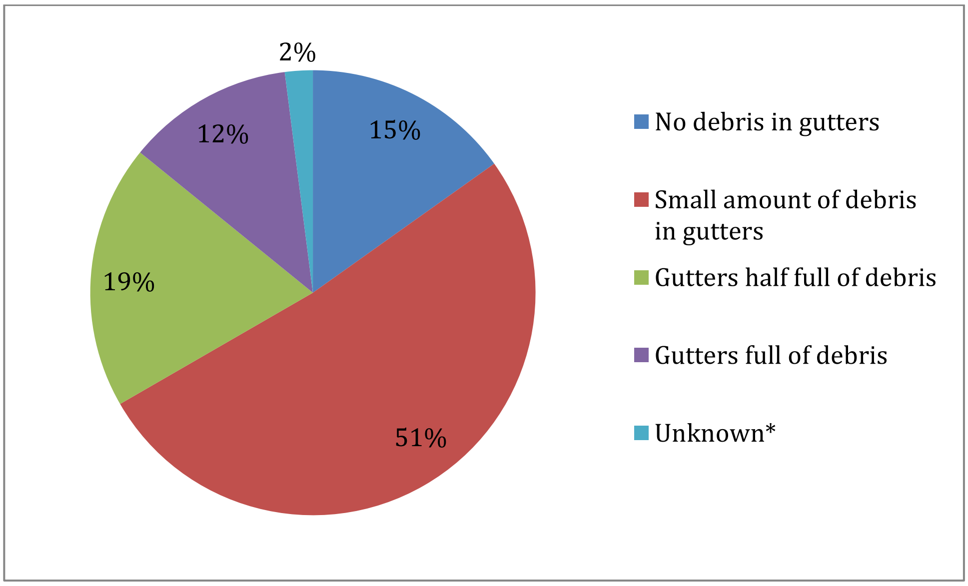



Figure 36: Quantity of debris in gutters

***Note**: In some locations, primarily due to access problems or covered gutters, it was not possible to evaluate the quantity of debris. In all other cases, the amount was judged based on a video recording along the gutter.

## 4.10. Foundations

The stability of a tank is dependent on its foundations. Figure 37 shows that 51% of tanks were on level foundations, 42% were on unleveled foundations but were stable and 6% were on hazardous foundations. Hence whilst majority of tanks appeared stable, the foundations of half of the tanks were not level as they should have been. Majority of the tanks inspected were self-standing (Figure 37). Of greater concern was that 13% of tanks were leaning against a structure, thus adding increased lateral strain onto it (Figure 38).

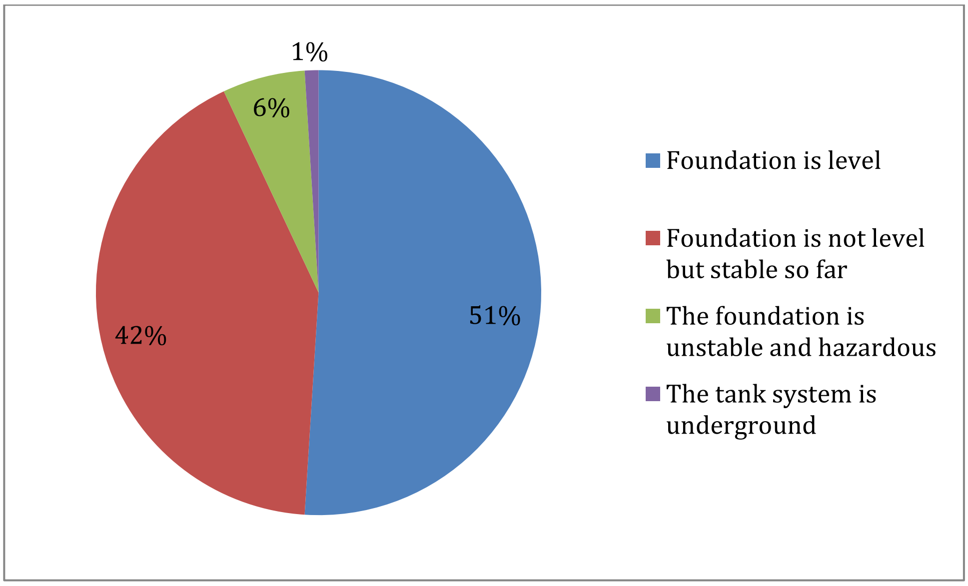



**Figure 37: Tank foundations being level or unstable**

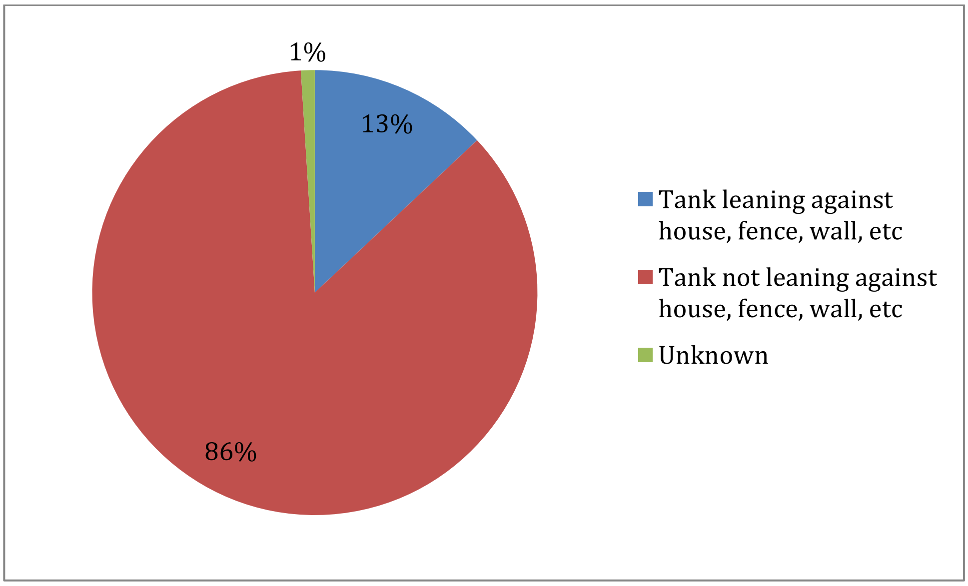



**Figure 38: Tanks leaning against objects**

## 4.11. Householder attitudes to their tanks

Attitudes of householders to their tanks are important because they will impact on the likelihood of adequate operation and maintenance of the rainwater tank systems; and are likely to have some influence on the ongoing uptake of rainwater tanks. These attitudes may also influence the way that householders use the rainwater from the tanks. Some of the general attitudes of owners towards their tanks were queried and the results are shown here.

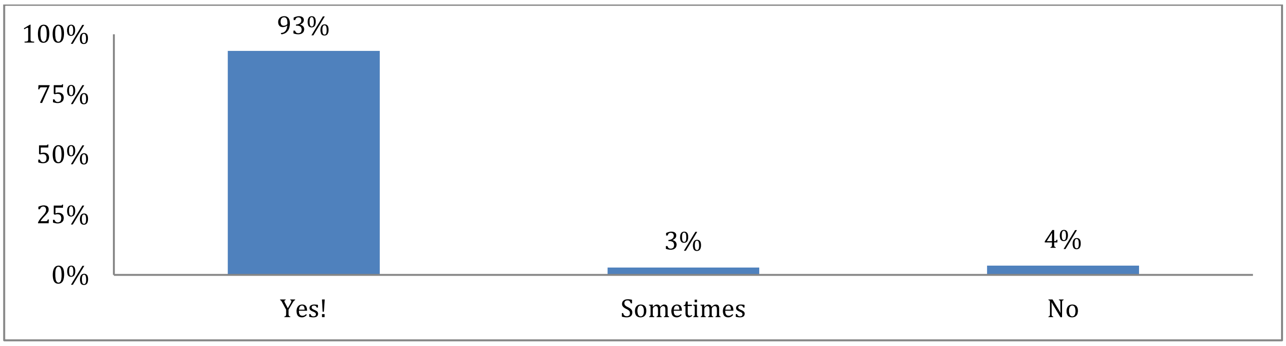



**Figure 39: Owners' satisfaction with their tank***

*** Question:** The question was: Are you satisfied with your rainwater tank overall?

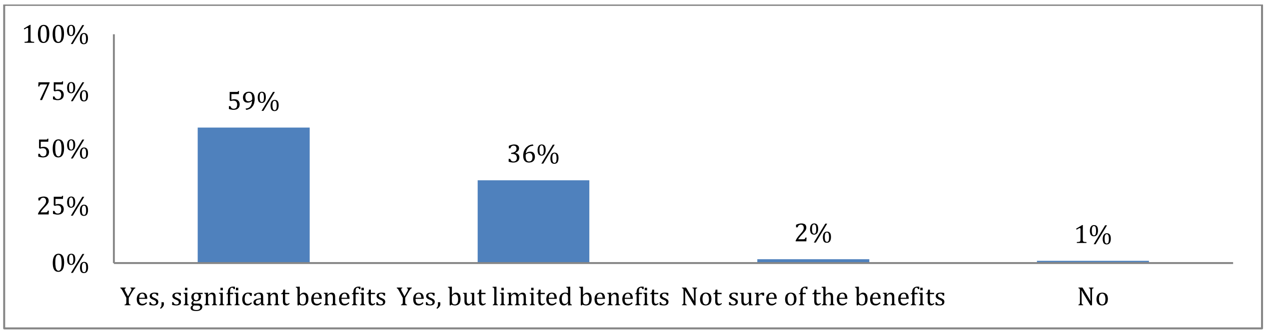



**Figure 40: Perception of private benefits from rainwater tanks***

***Question**: Do you think the rainwater tank brings your household benefits?

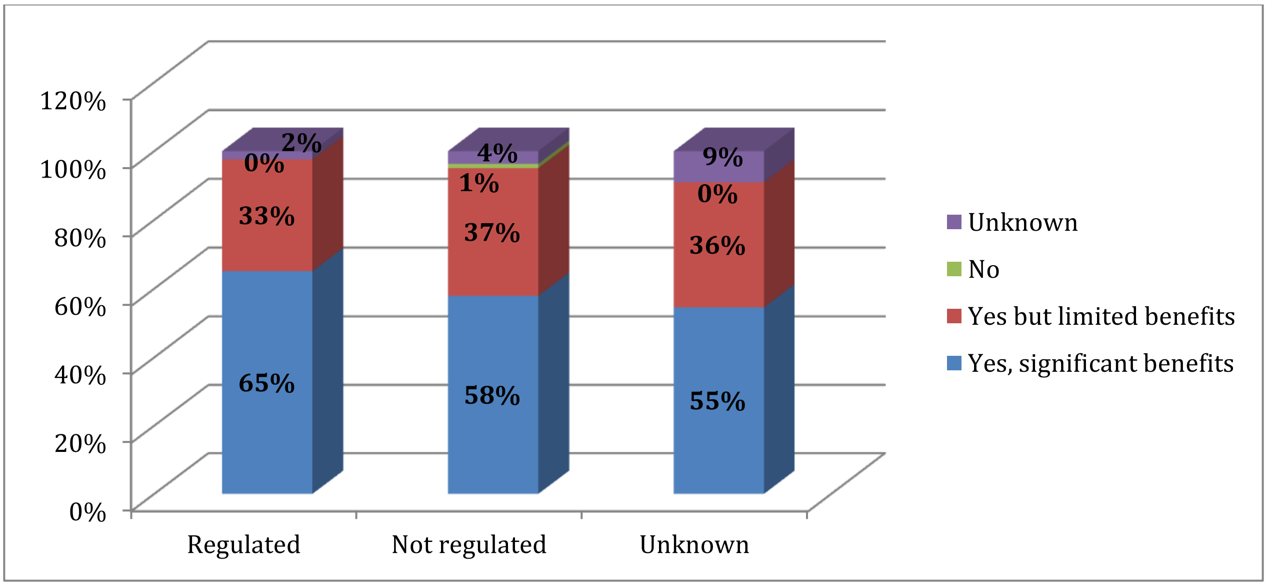



**Figure 41: Differences in perception of benefits for regulated and non-regulated tanks**

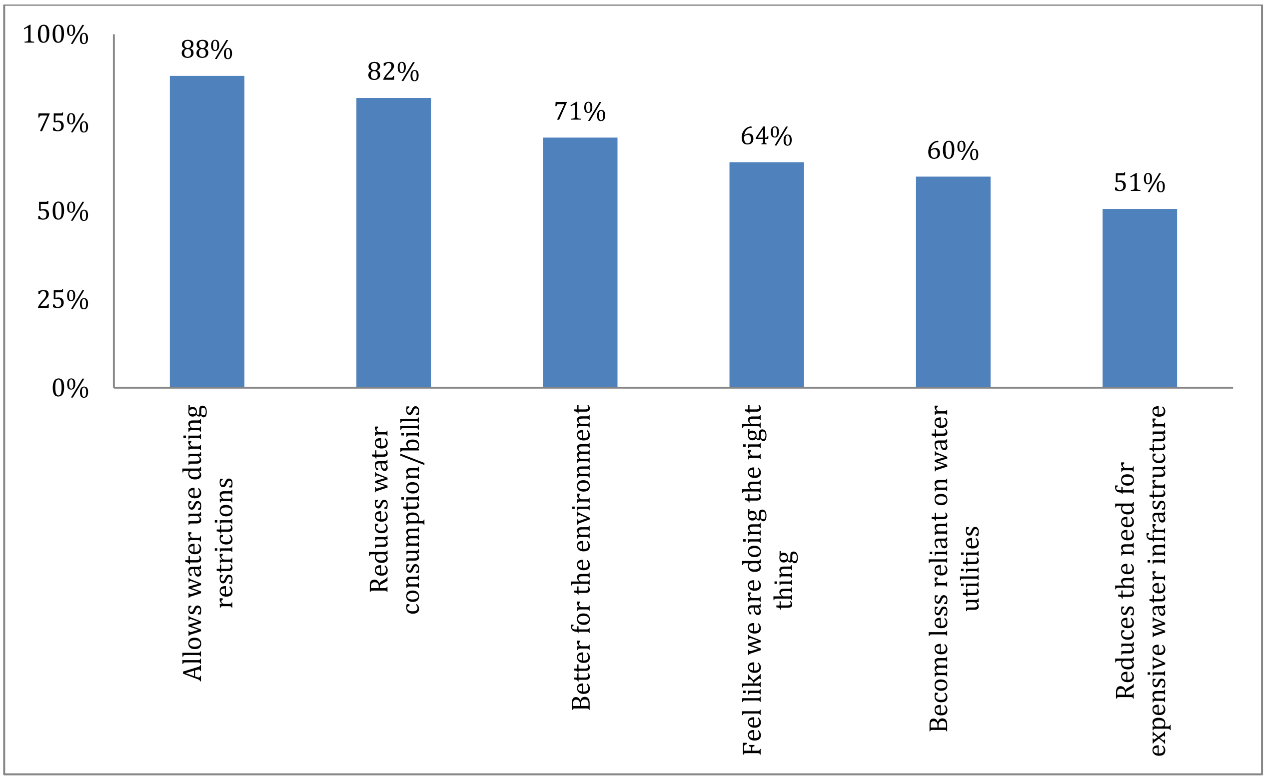



**Figure 42: Types of benefits from tanks***

***Question**: What type of benefits does your rainwater tank bring?

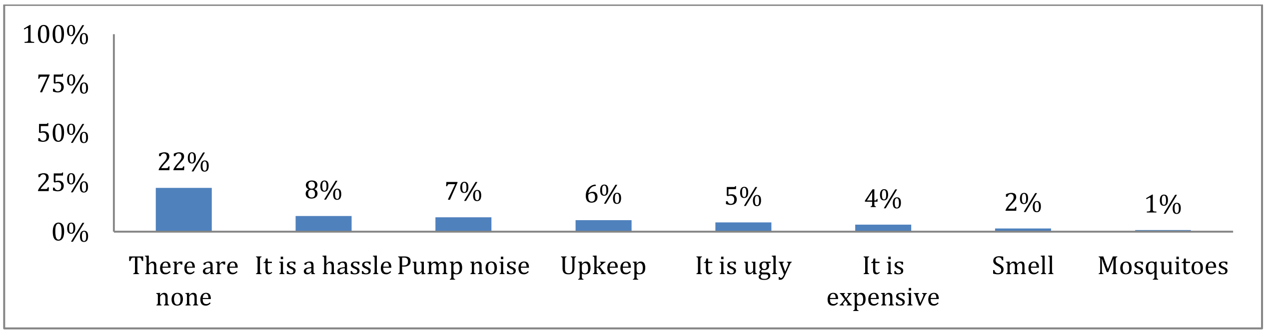



**Figure 43: Perceived negative aspects of rainwater tanks***

***Question**: In your experience what are the negative aspects of owning and operating a rainwater tank?

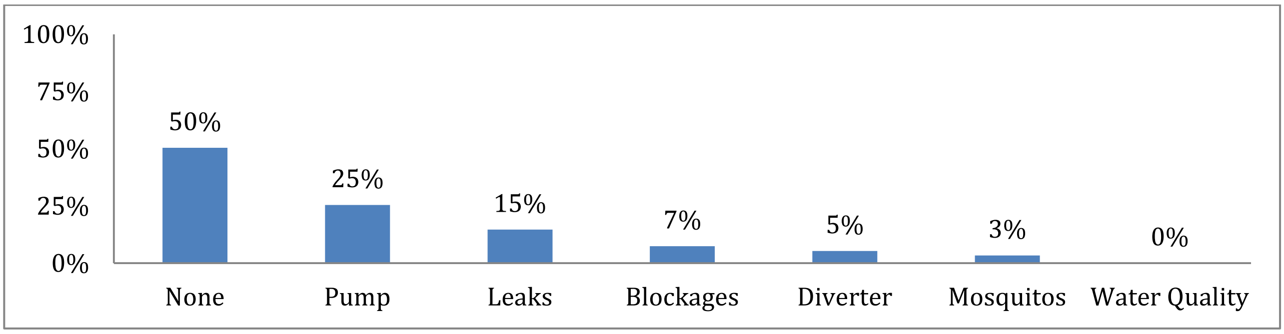



**Figure 44: Problems with tanks since installation***

***Question**: Have you had any issues with your rainwater supply system since installation?

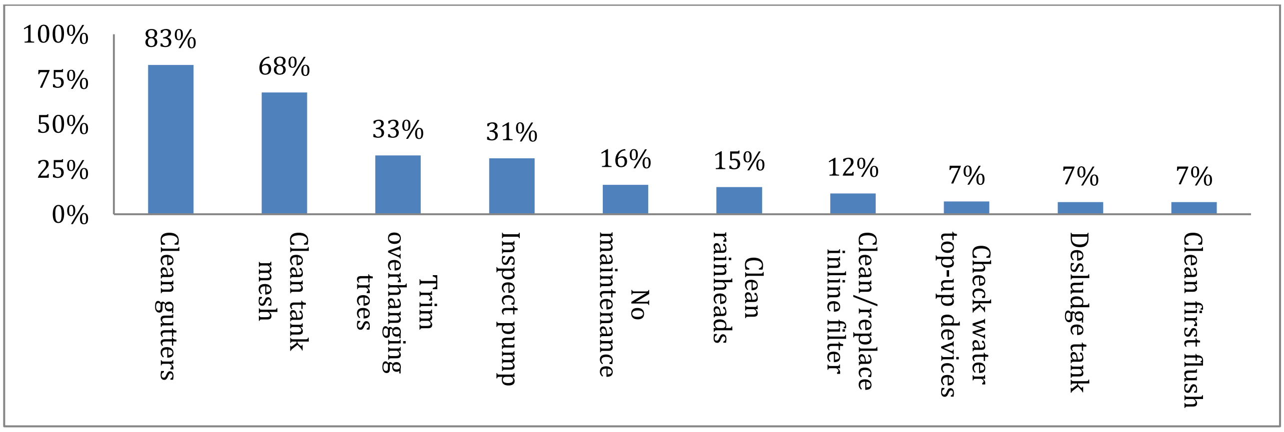



**Figure 45: Self-reported maintenance activities***

***Question**: What maintenance is carried out on your tank?

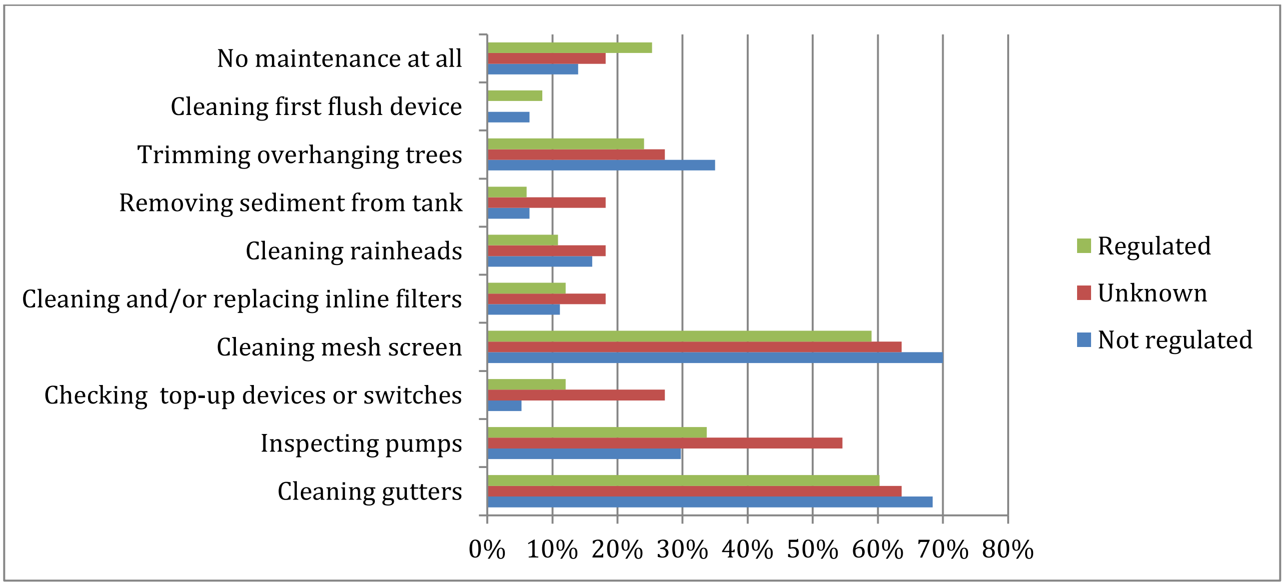



**Figure 46: Maintenance behaviours in regulated and non-regulated areas**

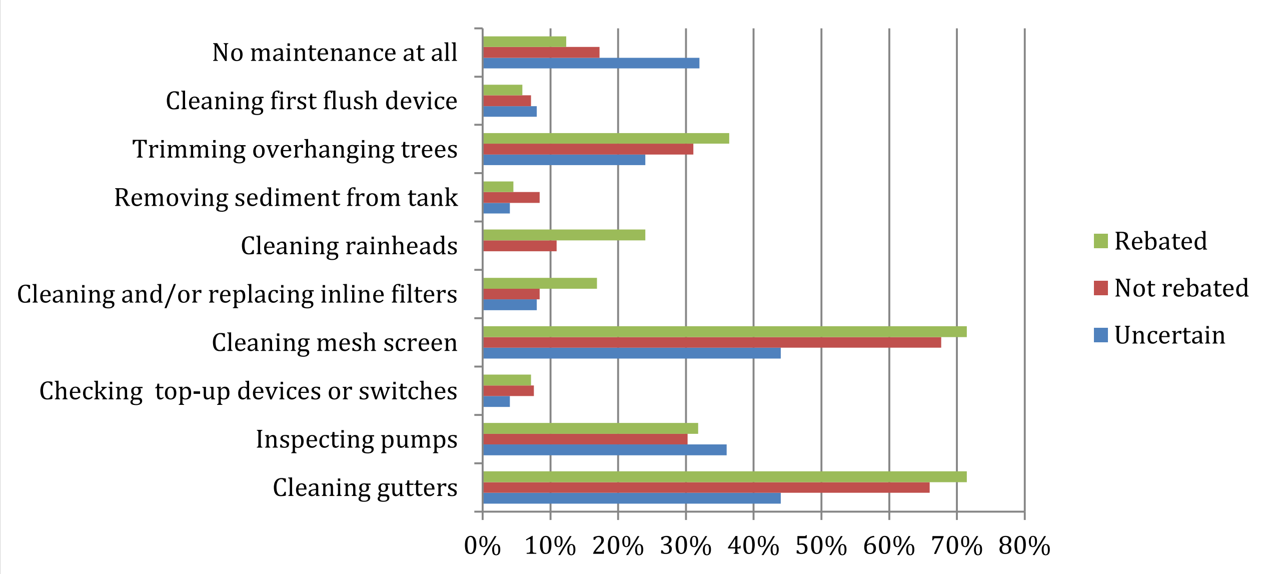



**Figure 47: Maintenance behaviours for rebated and non-rebated tank owners**

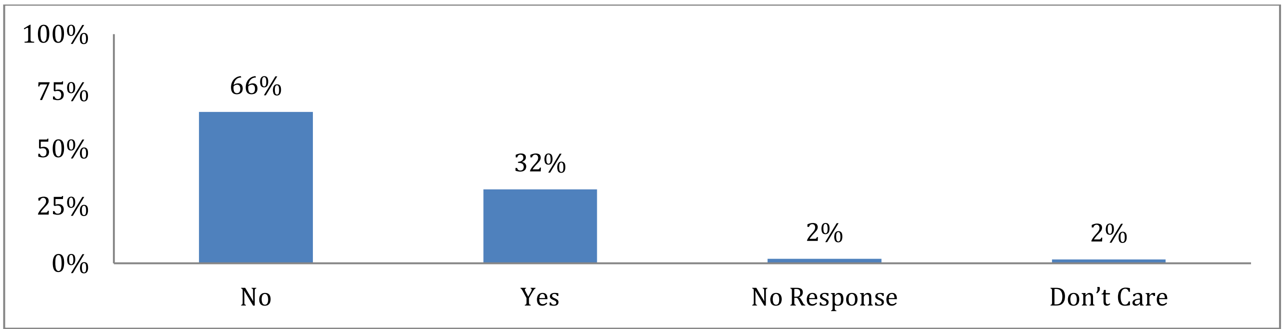



**Figure 48: Self-reported knowledge of maintenance activities***

***Question**: Do you know what maintenance is required for your rainwater tank?

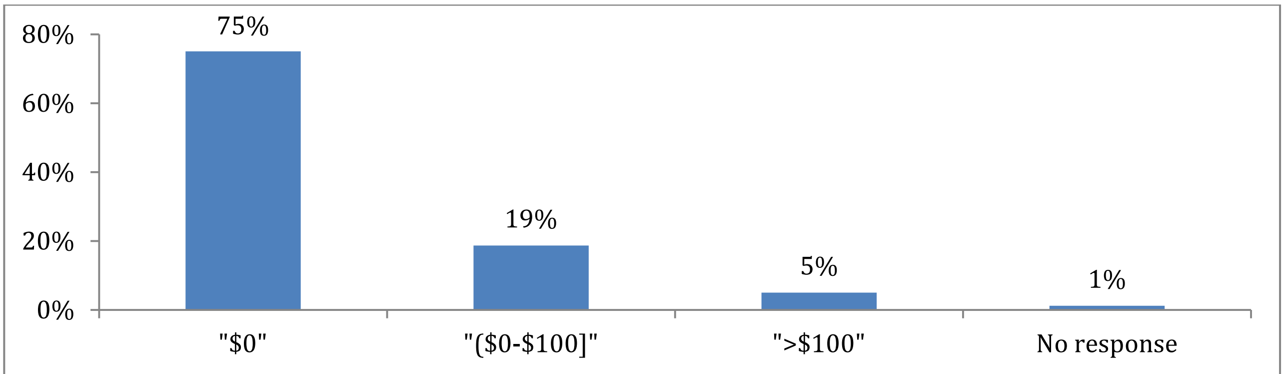



**Figure 49: Average annual maintenance expenditure. The average was $23.***

***Question:** Approximately how much do you spend on maintaining your tank in an average year?

## 4.12. Condition survey bias

A number of different approaches were employed for recruitment of participants to the condition survey; potentially generating some bias. Appendix H shows some of the basic properties of the respondents, showing that they are in general older than the average community member, somewhat more females than males have participated, primarily households with no children have participated, participants have in general lived for a relatively long time at the site of inspection, and the number of residents onsite generally vary between 1 and 4. This is not really unexpected as the surveyors have reported that elderly community members have in general shown a greater interest in the study and have to a greater extent been able to be on site to allow the inspection to be undertaken. It is also possible that the recruitment of participants may have generated some bias in the type of tanks that we have been inspected. Therefore, a comparison is provided with the Water Appliance Stock Survey and Usage Pattern Melbourne 2012 (Ghobadi, 2013, Quilliam, 2012, Gan and Redhead, 2012). This shows that there is some level of discrepancy between the two surveys. Smaller tanks were to a lesser extent picked up in this survey when compared to the water appliance stock-take (see Figure 50), and it is assumed that householders with such small tanks (up to 1kL) had less interest in their tank and thus in participating in the survey. The surveyors reported that a commonly stated reason for participating in the survey was a level of curiosity about the tank, and a desire to make sure it is working well. It is also notable that the recent ABS survey (Australian Bureau of Statistics, 2013) found that 29.2% of tanks were plumbed into the house for internal use purposes whilst in the Rainwater Tank Condition Survey of this report, 51% of households had plumbed their tank into the house for internal use purposes. This shows a bias towards tanks plumbed for indoor purposes. The same ABS survey also found that 77.6% reported not to have had any problems with their rainwater tank, whilst in our survey only 50% reported to not have had any problems with their tank.

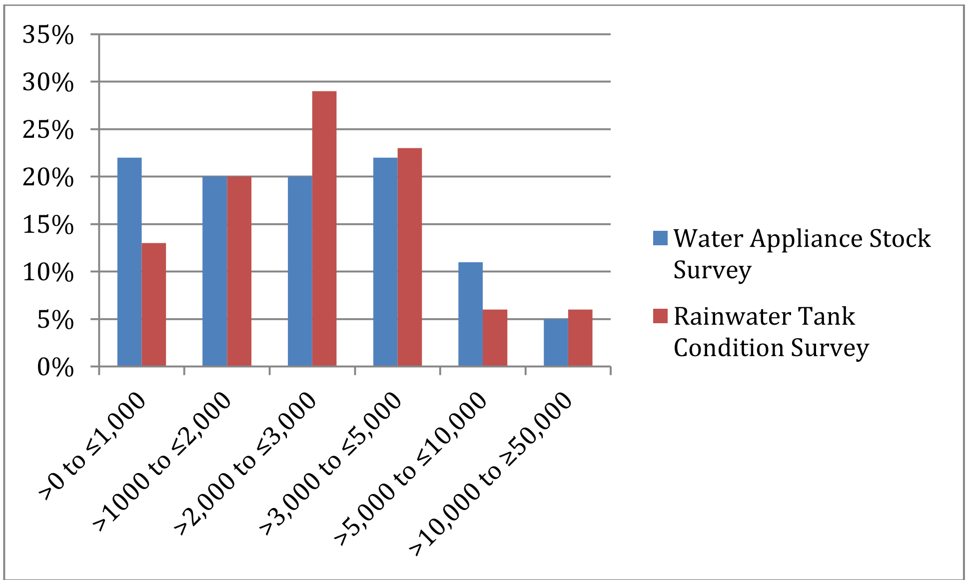



**Figure 50: Comparison between tank sizes in relation to water appliance stock take 2012**

This level of bias shows that whilst conclusions based on sub-categories should in most cases be reliably made using the data in this survey such as rates of faults for regulated vs. rebated tanks etc. However, it is more difficult to make inferences on the proportions of high level categories; such as penetration rates of regulated tanks and rebated tanks. It also seems likely that participants in this survey are more involved and interested in the management of their tanks than the average rainwater tank owner. This is an inevitable bias if participation is not mandatory.

## 5. Metering Results

The setup of rainwater tank systems as well as the metering approach differs between sites. For example, depending on how the rainwater tank(s) are used and how they are connected. Some key aspects of the tank system setups in the different sites can be found in Table 28.

**Table 28: Setup characteristics in different sites**

| Site ID | Nearest BOM* station | Number of householders | Use of rainwater | Waterswitch model | Mains top-up or switch | Issues during metering |
|---|---|---|---|---|---|---|
| 1 | 086104 | 2 | Indoor only | Rainbank | Mains switch | |
| 2 | 86074 | 4 | Indoor only | Manual | Manual switch | Mains meter broken during metering period. |
| 3 | 86210 | 2 | External only | Magstorm | Mains switch | |
| 4 | 86079 | 4 | External only | No mains supply | Neither | |
| 5 | 86096 | 1 | Indoor and outdoor | Aquasource | Mains switch | |
| 6 | 86039 | 3 | Indoor and outdoor | Rainbank | Mains switch | Switch broken |
| 7 | 86299 | 4 | External only | | Neither | Electricity Meter Broken |
| 8 | 86074 | 2 | Indoor only | Rainbank | Mains switch | Switch broken, replaced with 3-way valve |
| 9 | 86039 | 4 | Indoor and outdoor | Rainbank | Mains switch | Switch broken |
| 10 | 86039 | 2 | Indoor and outdoor | Unknown | Mains switch | Switch broken |
| 11 | 086104 | 1 | Indoor and outdoor | Rainbank | Mains switch | Switch broken |
| 12 | 86299 | 5 | Indoor and outdoor | No mains supply | Neither | Electricity Meter Broken |
| 13 | 86020 | 2 | Indoor and outdoor | Manual | Manual switch | |
| 14 | 86096 | 3 | External only | ClayTech | Mains switch | |
| 15 | 86038 | 3 | Indoor only | | Neither | Main meter not registering. Pump turned off. |
| 16 | 86244 | 4 | Indoor and outdoor | Rainbank | Mains switch | Bladder tanks with possible leak |
| 17 | 86074 | 4 | Indoor and outdoor | Rainbank | Mains switch | |
| 18 | 86079 | 2 | Indoor and outdoor | Power | Mains switch | |
| 19 | 86020 | 2 | Indoor and outdoor | Manual Apex RainAid | Top-up | |
| 20 | 86039 | 2 | External only | Superior Pump SP70 | Mains switch | |
| 21 | 86035 | 4 | External only | | Neither | Pump broken |

*Note: BOM is a reference to the Bureau of Meteorology. Their weather station directory is available at http://www.bom.gov.au/climate/data/stations/. There is daily rainfall data available for all these weather stations.

There are three ways in which these tank setups utilize mains water in the event that the rainwater tank would run dry:

- Mains top-up will fill up the tank if the water level drops below a certain level.
- Manual switches require the owner to physically switch so that mains water is used in the event that the rainwater tank is dry.
- Automatic main switches operate in a way by which mains water will be used automatically when the rainwater tank is dry.

A number of types of flow meters were installed in the sites (Umapathi et al., 2013):

- **TM**: The 'total mains' is the total potable mains water being utilized in the household, supplied from the water utility's system measured at flow meter. In dwellings with plumbed rainwater tanks, TM is the only source of potable water supply to internal household fixtures such as showers, cooking/drinking, internal faucets and others. Rainwater is supplied to external garden taps, flushing of toilet cisterns and cold tap of wash machines, where the potable mains water acts as secondary water source when rainwater is not available. Only At sites with compatible main meters, the potable water flowing into the site is being monitored.
- **MWTU**: The household plumbed rainwater tank system incorporates mains water top-up or an automatic switch, which prevents any interruption in water supply during the absence of rainwater source. In this study, there are two types of top-up systems present. One home operate on the "trickle top-up" mechanism a larger number use "rainwater switch" mechanism, for back-up supply to their rainwater tanks. Rainwater tank systems employing the trickle top-up mechanism operate on a "float" arrangement, whereby every time there is a drop in rainwater level below a stipulated point in the rainwater tank, a fixed volume of mains water is delivered into the tank. This system is regulated by a valve, which is activated by a float, which in turn either starts or stops the mains water supply into the tank. However, in rainwater switch system, mains water bypasses both the tank and pump systems and delivers directly to the connected end-uses without entering the tank, until there is sufficient rainwater available in the tank.
- **GT**: External water usage or water supply to garden tap. The GT stream is the water supply from rainwater tank to external garden taps installed for outdoor gardening or car washing purposes. All garden taps supplied water from the plumbed rainwater tank systems at the monitored households. The water supply to the garden taps was also monitored to determine external end-use water demand.
- **EU**: The energy usage/requirement to pump water from the rainwater tank system into designated household end uses was also monitored in order to determine the energy efficiency of each system and to correlate to the factors influencing the energy efficiency, such as top-up type, water supply/demand patterns and pump suitability, etc.

For further details regarding reasoning behind metering set-ups, see Umapathi et al. (Umapathi et al., 2013, Umapathi et al., 2012). Partly because of the different setups, and partly because of the practical limitations of each site, there are different combinations of meters and loggers, as per Table 29. Therefore, we describe the results for each of the 21 sites in some detail before moving on to summary results.

**Table 29: Metering setups in sites**

| Site ID | Use of rainwater | Total mains (TM) | Total rainwater (TORW) | Mains switch / topup (MWTU) | Garden tap (GT) | Electricity meter (EU) | Depth probe |
|---|---|---|---|---|---|---|---|
| 1 | Indoor only | | √ | √ | | | √ |
| 2 | Indoor only | Partial*** | √ | | | √ | |
| 3 | External only | Partial*** | | | √ | √ | √ |
| 4 | External only | √ | | | √ | √ | √ |
| 5 | Indoor and outdoor | Partial*** | √ | √ | √ | √ | √ |
| 6 | Indoor and outdoor | √ | √ | √ | √ | √ | |
| 7 | External only | √ | √ | | √ | √ | √ |
| 8 | Indoor only | √ | √ | √ | | | Partial |
| 9 | Indoor and outdoor | √ | √ | √ | √ | √ | √ |
| 10 | Indoor and outdoor | Partial*** | √ | √ | √ | √ | √ |
| 11 | Indoor and outdoor | Flow meter not working | √ | √ | √ | √ | √ |
| 12 | Indoor and outdoor | Partial*** | √ | | √ | √ | √ |
| 13 | Indoor and outdoor | √ | √ | | √ | √ | |
| 14 | External only | √ | √ | | √ | √ | √ |
| 15 | Indoor only | | √ | | | | √ |
| 16 | Indoor and outdoor | | √ | √ | √ | √ | |
| 17 | Indoor and outdoor | | √ | √ | √ | √ | √ |
| 18 | Indoor and outdoor | | √ | √ | √ | √ | √ |
| 19 | Indoor and outdoor | | √ | √ | √ | √ | √ |
| 20 | External only | | √ | | | √ | |
| 21 | External only | | √ | | | √ | √ |

***Note**: In these sites, it was not possible to fit a logger and meter next to the main meter for a range of reasons.

****Note:** The mains meter for this site was only logged for part of the year.

*****Note**: Only for part of the metering period.

## 5.1. Data errors and issues

The metering and logging equipment is unfortunately not completely reliable at all times. There are some types of problems that have occurred:

- Loggers submit signals on a regular basis via the mobile phone network to online servers where the data is stored. At times, there may be interruptions to the mobile phone reception which combined with the limited data storage capacity of loggers, can cause gaps in the data recorded.
- Similarly it has been found that mobile phones can interfere with metering equipment; causing recordings of "very large" flows. Whilst it could be difficult to distinguish between real flows and erroneous flows, these "very large flows" are physically impossible. In the analysis of the metering data this has been taken into account by ignoring any recorded flows larger than 100 liters per minute.
- It appears that the meters connected to garden taps have in many instances been recording zero flows even when flows have occurred. The reasons for this are unknown, but in these events, flow data can be mapped against depth gauge data which can be used to estimate rainwater use.

## 5.2. Using depth gauge data

The depth data provides tank water depth in millimeters every 15 minutes. The accuracy of readings are +/- 1 mm. By using the depth data to estimate volumes of water into the tank and out of the tank, using basic volumetric calculations it is possible to estimate the rainwater use:

$$V_{change} = \Delta \cdot A \qquad (1)$$

Where Δ is the change of water level, and A is the base area of the rainwater tank (estimated using geometrical properties or by dividing the volume of the tank with the height of the tank). $V_{change}$ represents water use when negative and inflows when positive. Changes of less than 5 mm (i.e. $\Delta<5$) are ignored as possible errors due to measurement inaccuracy and/or any evaporation losses.

There are usually discrepancies between water usage estimates based on depth gauge data, and those based on flow meters. The following can be the possible factors explaining the discrepancies:

- Non-pressurized rainwater use is not likely to be picked up by flow meters. There are also ways of using rainwater that is not going through metered taps. Flow meters sometimes show extra outflows during the summer months in excess of what flow meters have picked up which can be explained by this type of rainwater use, for example trickle feed watering practices.
- Flow meters are not able to pick up leakages from the rainwater tanks. Depth gauge measurements may pick up this type of change however (depending on the flow rate of the leakage); but in such cases without letting the analyst distinguish between usage and leakage.
- Depth gauge measurements with 15 minute time intervals do not provide accurate information for estimating rainwater use during rainfall events. During these times this ought to lead to some degree of under-estimation of the rainwater use.
- Both the flow meters as well as the depth gauge measurements have inherent measurement errors.

## 5.3. Individual metering site results

Each of the individual sites has quite different set-ups and situations and thus there is benefit in providing such results specifically. These results are shown in the following sub-sections.

### 5.3.1. Site 1

Site 1 has two inter-connected rainwater tanks installed approximately 6 years ago; with a total volume of 7 kL. Rainwater is used for indoor purposes primarily with a Davey HP45-05 pump and an automatic mains switch. The professionals who installed the metering equipment estimated that 13% of the roof area is connected; although the owner estimated that 40% of the roof area is connected to the tank. It was found that there are 5 downpipes on the house and only one of these is connected to the rainwater tank. In this site, the main meter is not loggable.

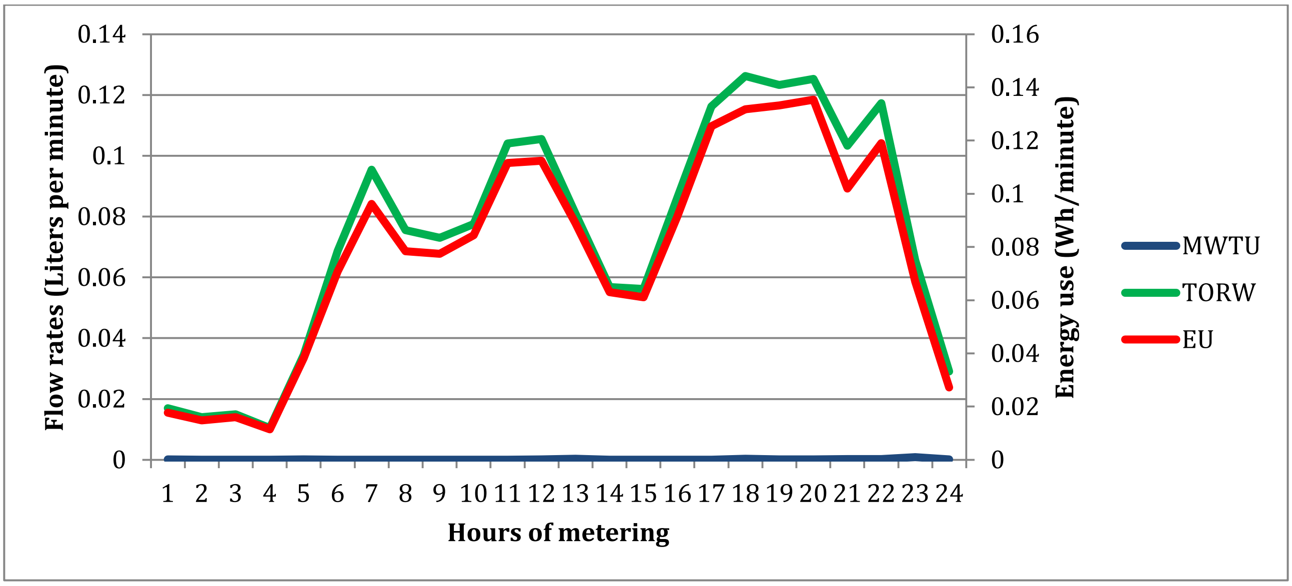



Figure 51: Hourly profile of metered data for Site 1

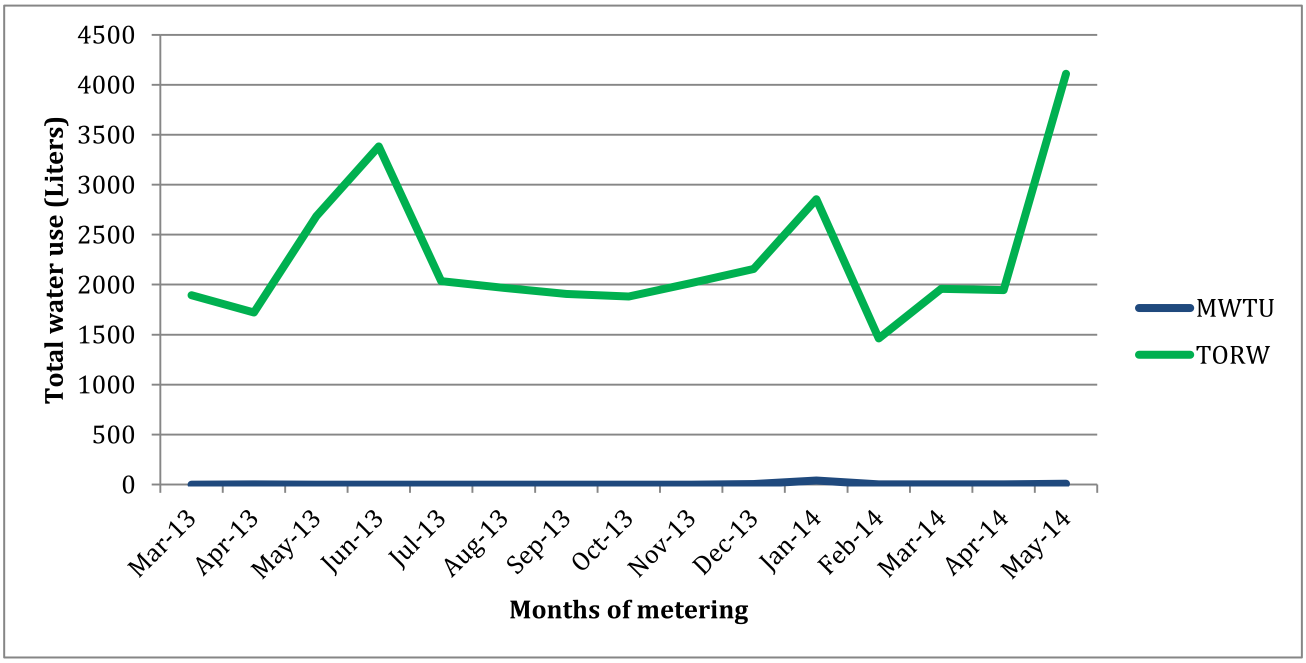



Figure 52: Monthly profiles for metered data in Site 1

It is worth noting that the automatic switch for using mains water has not been activated except for a short time in January 2014. The depth gauge data shows that the water level indeed dropped to near empty in May 2013 (see Figure 53). The complete depth gauge data is yet to be uploaded.

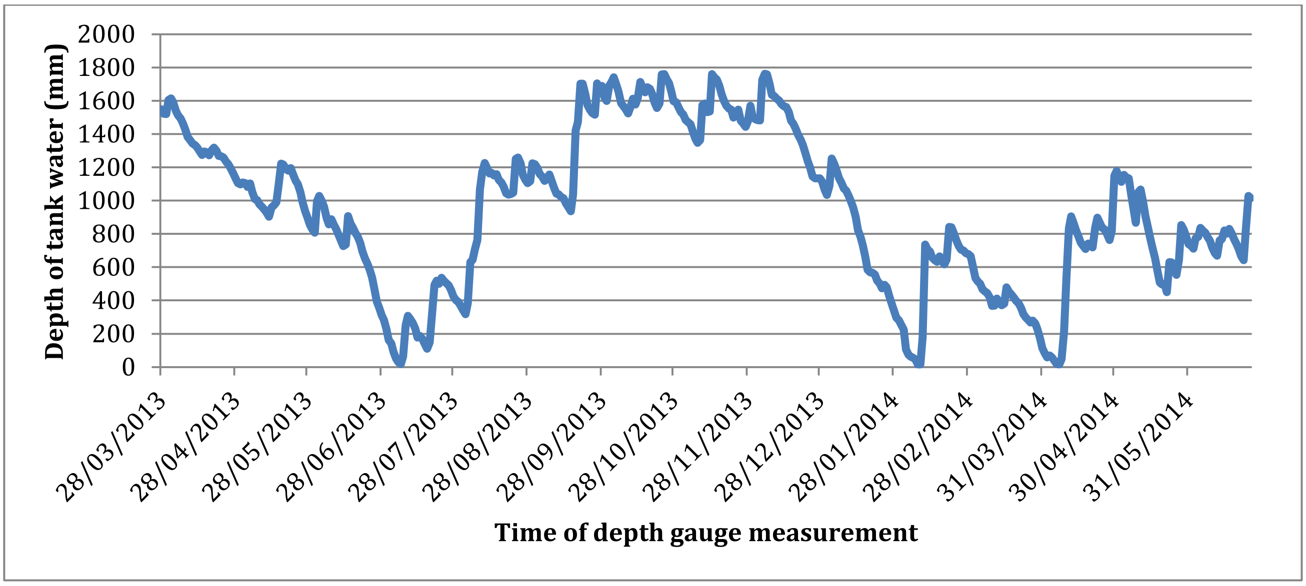



**Figure 53: Depth gauge data (Site 1)**

The estimated water savings for the full time of depth gauge measurement (28th March 2013-26th June 2014) is 42 kL, and for the 12 months starting in April 2013 is 33 kL. There is some discrepancy between the flow meter estimates and the depth gauge measurements of rainwater use, as per Figure 54.

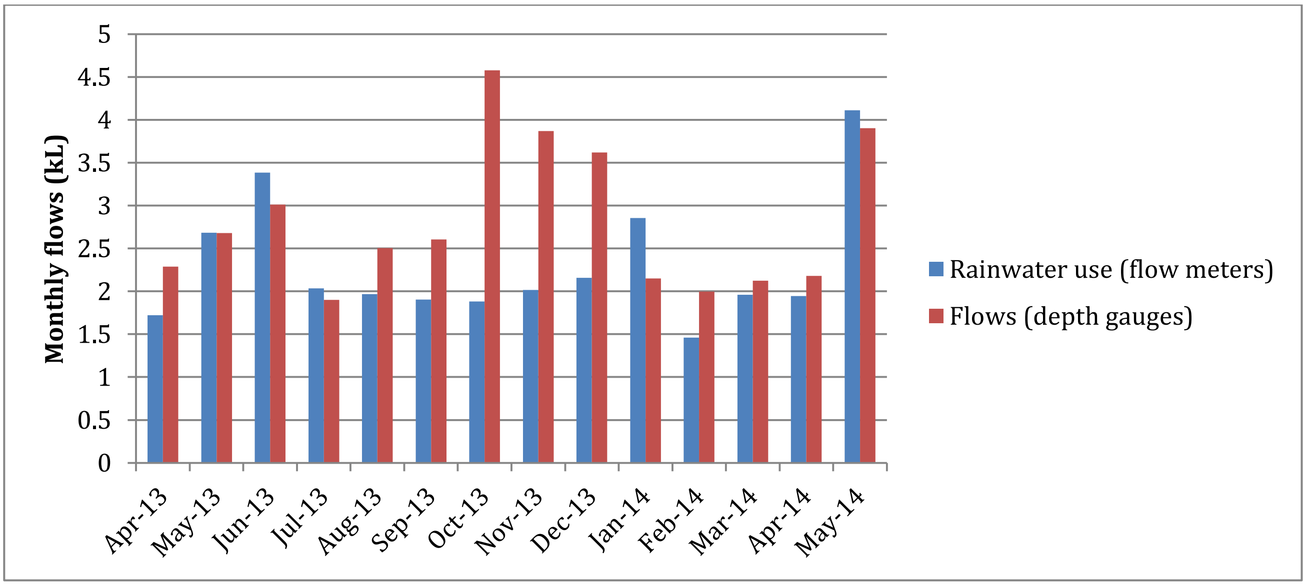



**Figure 54: Monthly estimates of rainwater use***

***Note**: It noted that estimated usage during the summer months based on depth gauge measurements significantly exceeds that of estimates based on flow meters. The working hypothesis is that this is due to non-pressurized use of rainwater for the purposes of watering the garden or filling up a pool etc.

As per Table 30, the total water savings from the rainwater tank over the full metering period in this site is 34 kL (using flow meter estimates); the annual savings over the first 12 months of metering is 26 kL. The specific energy for the pump is relatively low at 1.1 kWh/kL.

Table 30: Summary variables for Site 1

| Metered variable | Total over the metering period* | Total over the first 12 months* |
|---|---|---|
| Total Rainwater Use (TORW) | 34.0 kL | 25.9 kL |
| Mains water topup (MWTU) | 56 liters | 44 liters |
| Energy use (EU) | 36.5 kW | 27.7 kW |
| Specific energy (EU/TORW) | 1.1 kWh/kL | 1.1 kWh/kL |

***Note**: The full metering period was 1/3/2013 to 1/6/2014. The first 12 months are March 2013-February 2014.

### 5.3.2. Site 2

Site 2 has one cylindrical tank installed approximately 9 years ago; with a volume of 16.9 kL. Rainwater is used for a number of indoor purposes: laundry, bathroom and everything but kitchen sink, bathroom sink and the hot water system. The tank provides water for outdoor purposes as well. The pump type is Slaters X01-HMP25\5M-GC: HMP25-5M and there is no automatic mains switch. The pump was out of service until May 2013. The householders switch the power of the pump when they want to use the water. The professionals who installed the metering equipment estimated that 60% of the roof area is connected; although the owner estimated that 100% of the roof area is connected to the tank. It was found that there are 3 downpipes on the house and only one of these is connected to the rainwater tank. Another notable issue is that this site is the only metered site without a leaf guard. Unfortunately it was not possible to monitor the water levels in this site.

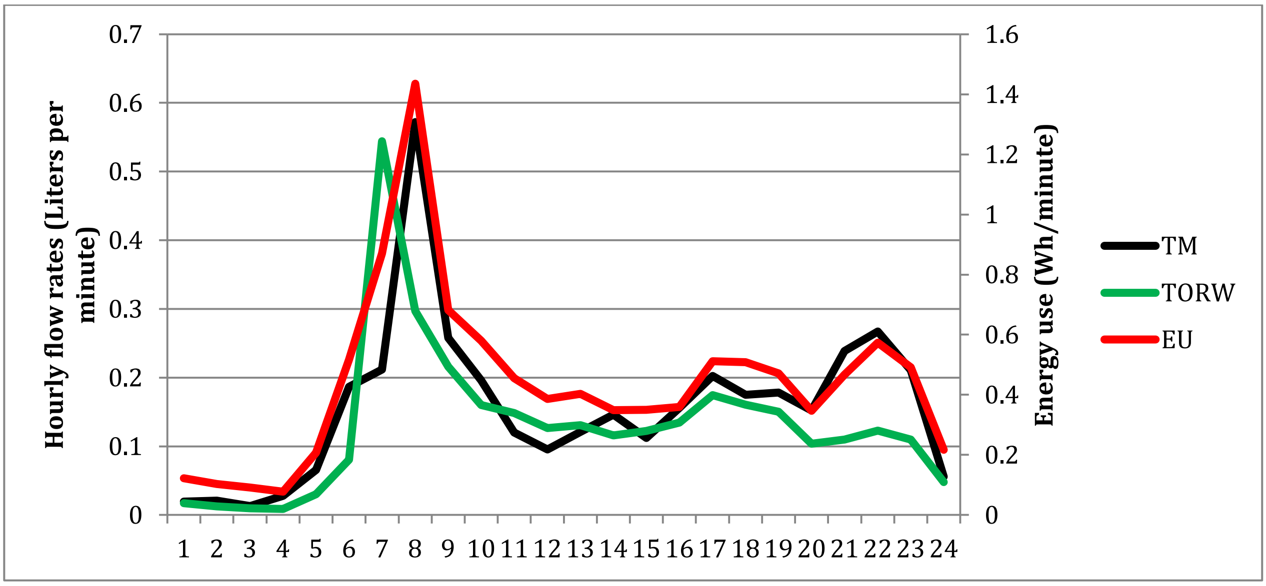



Figure 55: Hourly profile of site 2

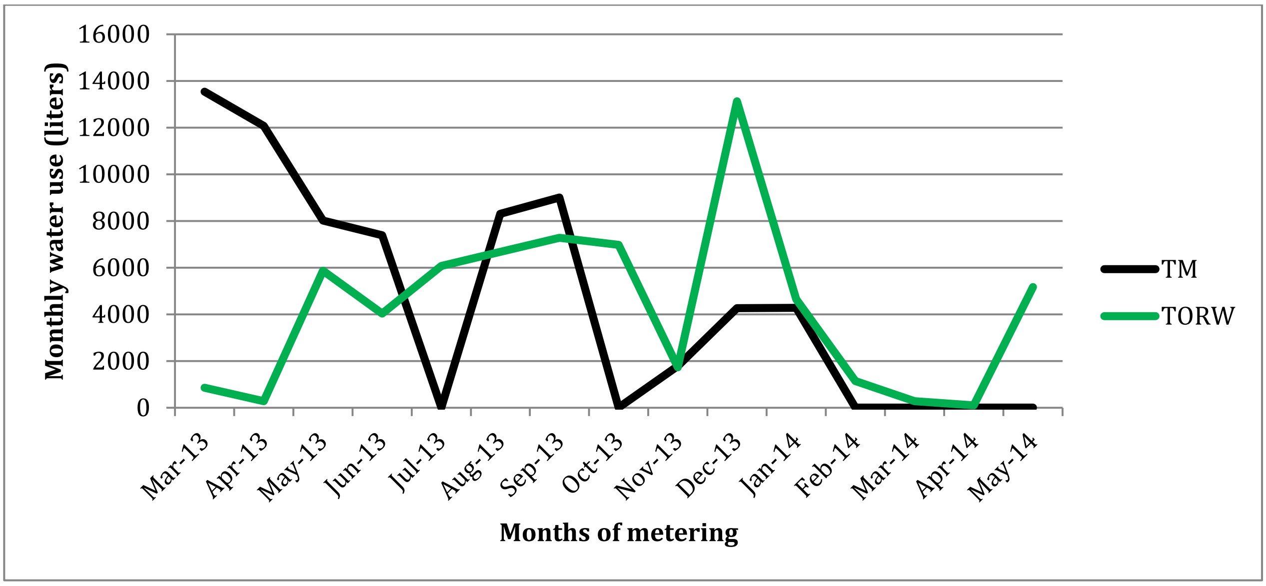



**Figure 56: Monthly profile for site 2**

This site has performed very well with solid rainwater usage over the metering period. It is also noted that the specific energy for this site is unusually high (in fact about twice the amount expected in the higher range of specific energy in previous studies). This leads us to a suspicion that not all rainwater usage has been metered and indeed no outdoor usage has been metered. It is plausible that almost as much rainwater has been used for outdoor purposes as has been used for indoor purposes at this site. However it is not possible to confirm this suspicion based on depth gauge data.

**Table 31: Summary variables for Site 2**

| Summary variable | Total over the metering period* | Total over the first 12 months* | Total whist mains flow meter was operating** |
|---|---|---|---|
| Total Rainwater Use (TORW) | 64.2 kL | 58.7 kL | 52.9 kL |
| Total Mains (TM)** | N/A | N/A | 64.4 kL |
| Volumetric reliability (TORW/TORW+TM) | N/A | N/A | 45% |
| Energy use (EU) | 217.5 kWh | 194.1 kWh | 187.2 kWh |
| Specific energy (EU/TORW) | 3.4 kWh/kL | 3.3 kWh/kL | 3.5 kWh/kL |

***Note**: The full metering period was March 2013 – May 2014. The first 12 months were March 2013 – February 2014. There were gaps in the data EU, TORW: 14/01/2014, 0:12:00 - 17/01/2014, 0:01:00;

****Note**: The mains flow meter stopped working on 26th January 2014. There was also a considerable gap in all the data for a few days in January. Therefore this time period is March – December 2013.

### 5.3.3. Site 3

Site 3 has one rectangular tank of unknown age; with a volume of approximately 1.3 kL. Rainwater is used for external purposes only. The pump type is MAG STORM WP7200 and the system includes an automatic mains switch. The professionals who installed the metering equipment estimated that 20% of the roof area is connected. It was found that there are 5 downpipes on the house and only one of these is connected to the rainwater tank. The householder noted that the stormwater diverter was switched off from about March 2014 to avoid over-spilling. No water entered the tank from this time.

**Table 32: Summary information from metering at site 3**

| Summary variable | Total over the metering period* | Total over months when mains meter was operating** |
|---|---|---|
| Garden tap use (GT) | 2.4 kL | 1.1 kL |
| Total mains (TM) | N/A | 70 kL |
| Volumetric reliability (GT/TM+GT) | N/A | 1.5% |
| Energy use (EU) | 2.0 kWh | 0.9 kWh |
| Specific energy (EU/GT) | 0.8 kWh/kL | 0.8 kWh/kL |

***Note**: 12 months: June 2013 – May 2014.

****Note**: June – August 2013 & January – May 2014.

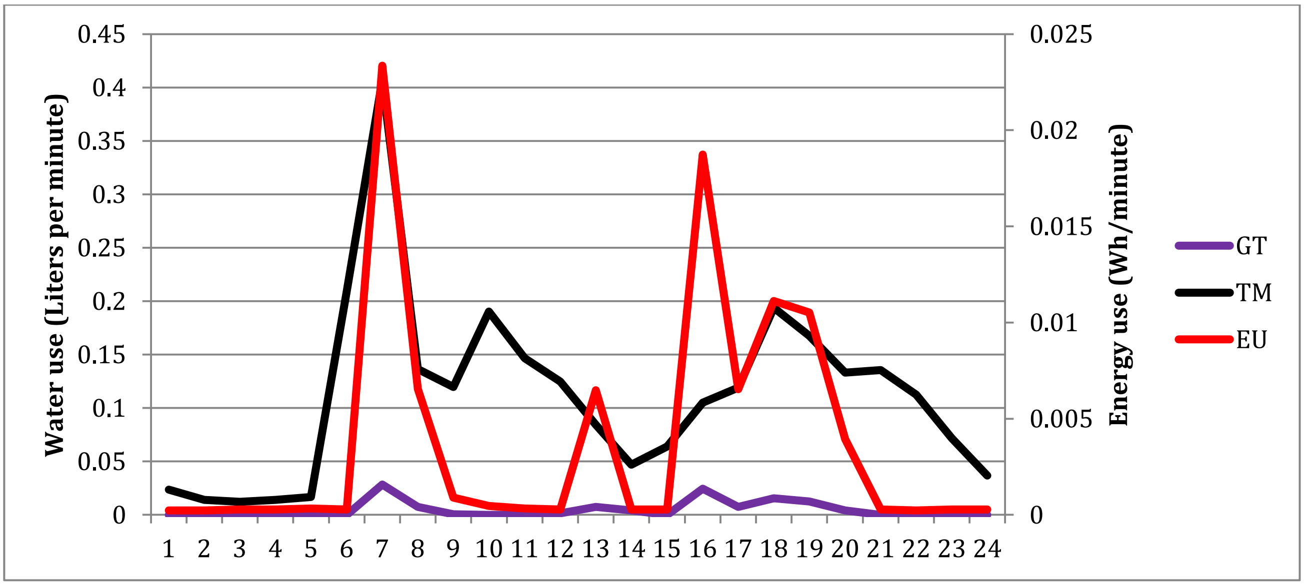



**Figure 57: Hourly profiles (site 3)**

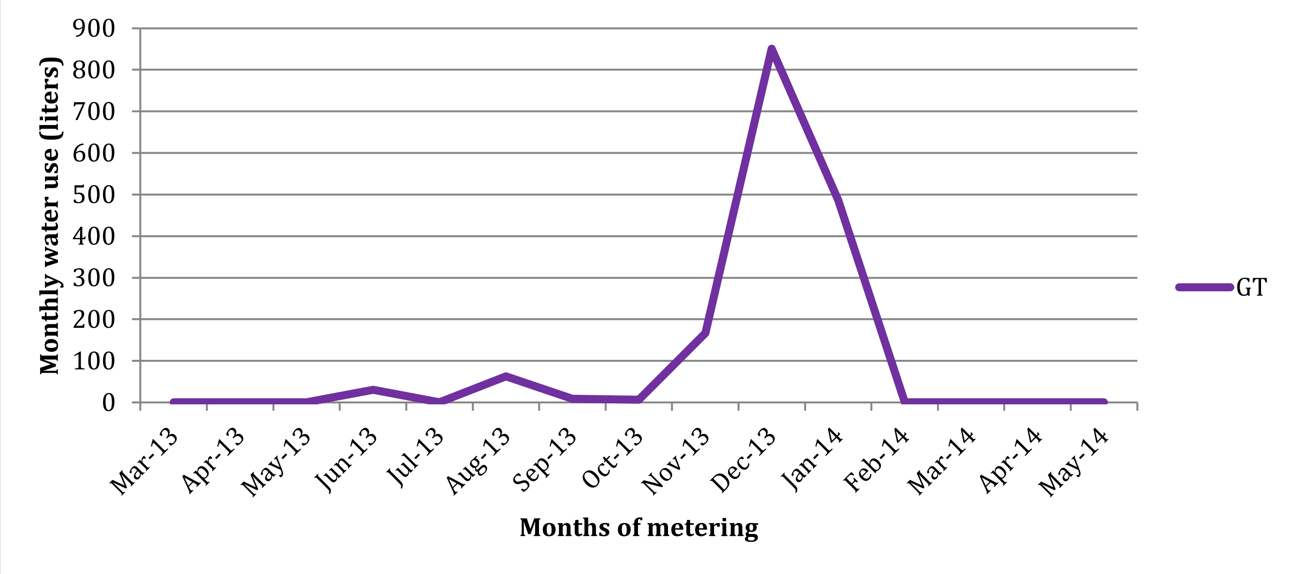



**Figure 58: Monthly profiles (site 3)**

It is noted that the overall total mains water into the house was only metered for part of the metering period, and that during this time the household water use was a mere 178 liters per day. The main rainwater use for this site is the garden tap, and as can be seen in Figure 58, this occurred primarily over a small time period over the dry and hot summer months. Furthermore, for this site there is access to depth gauge data (Figure 59) so that it is possible to cross-check metering results.

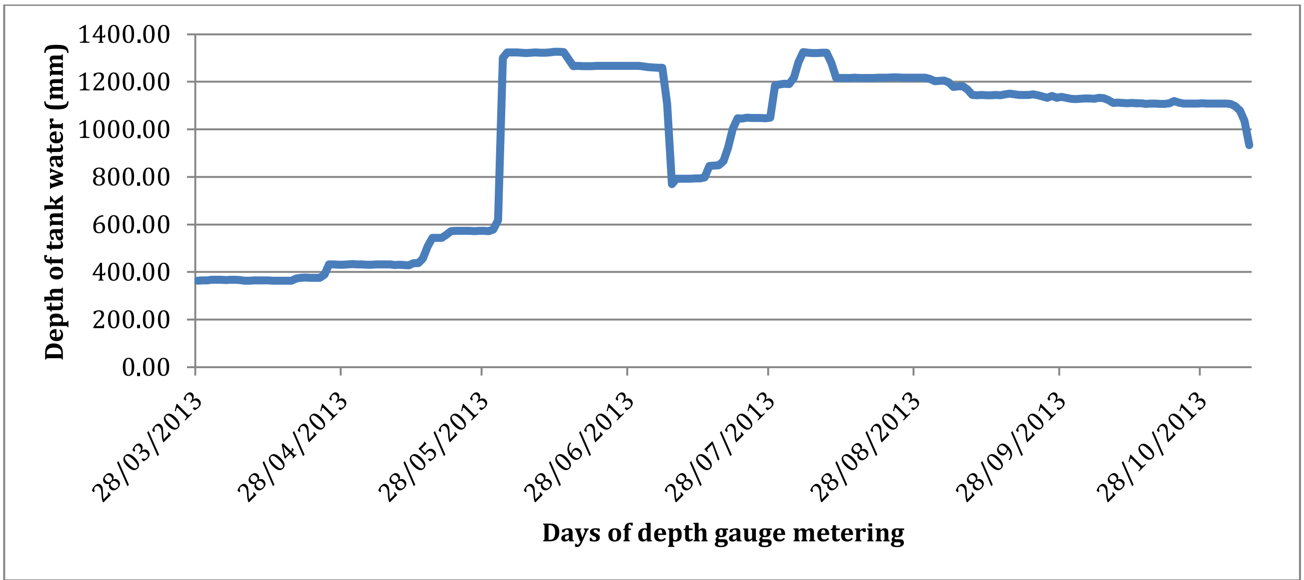



**Figure 59: Depth gauge data (Site 3)***

For the months of data where there are both depth gauge measurements and flow meter measurements, the flow meters estimate rainwater use at 0.28 kL and estimates based on the depth gauges indicate a rainwater use at 0.46 kL (the difference being 0.18 kL). However, much of the difference is due to a single usage event in July which depth gauges picked up, but which flow meters did not pick up. The volume of this usage event was approximately 0.24 kL. This event is likely to have been either due to leakage or at least water exiting the tank through a non-metered point. Depth gauge data also indicate that the tank was nearly full only approximately 10% of the time, and never close to empty. Based on the flow meter data, Table 32 provides some summary information from site 3.

### 5.3.4. Site 4

Site 4 has one cylindrical tank installed about 7 years ago with a volume of approximately 5.4 kL. This is a semi-rural property and rainwater is used for external purposes only. The owner has said that the major uses were topping up the pool, washing down stock trailer and farm vehicles and irrigating the fruit trees. The pump type is Universal UP-CM4-50-1and the system has no automatic mains switch. During the metering period, the owner had to make some repairs on the switch. The professionals who installed the metering equipment estimated that 50% of the roof area is connected. It was found that there are 5 downpipes on the house and only one of these is connected to the rainwater tank. As per Figure 60, whilst the flow meters have picked up total mains use, they have not picked up any rainwater use, or indeed any pump energy use. This is again evident in Figure 61. The participant in this site has clearly stated that there were significant amounts of rainwater use, and the installers of equipment have checked that the equipment was working. It is unclear why there is a discrepancy.

The summary variables based on the flow meter data is shown in Table 33, indicating zero rainwater use. The metering equipment was checked to see whether it was functional during the November 2013 visit. Flow meters were found to be operational. Whilst this result is remarkable, there is the suspicion about whether flow meters pick up all water use from the tank, and therefore it was also explored whether the depth gauge data which is shown in Figure 62 indicated any rainwater usage. The depth gauge data shows considerable draw-downs in the water levels in the tank (see Figure 62) and analysis of the depth gauge data for the time period 28$^{th}$ March– 21$^{st}$ July 2014 provided us with a different estimate of the total water use from this rainwater tank, i.e. 11.6 kL.

**Table 33: Summary information for site 4**

| Summary variable | Total over the metering period* | Estimates based on depth gauge data** | Estimate for 12 months* |
|---|---|---|---|
| Total rainwater use (TORW) | 0 kL | 60 kL | 48 kL |
| Total mains use (TM) | 598 kL | 598 kL | 318 kL |
| Volumetric reliability (TORW/TORW+TM) | 0% | 9% | 13% |
| Energy use (EU) | 0 kWh | 0 kWh*** | 0 kWh |
| Specific energy (EU/TORW) | N/A | 0 kWh/kL | 0 kWh/kL |

***Note**: This full metering period covers April 2013-May2014. The 12 months referred to are April 2013-March 2014.

*****Note**: Given that the energy meter did not show any energy use during the metering period, it will have to be assumed that any rainwater was extracted by means of gravity feed. The time period is March 2013-June 2014.

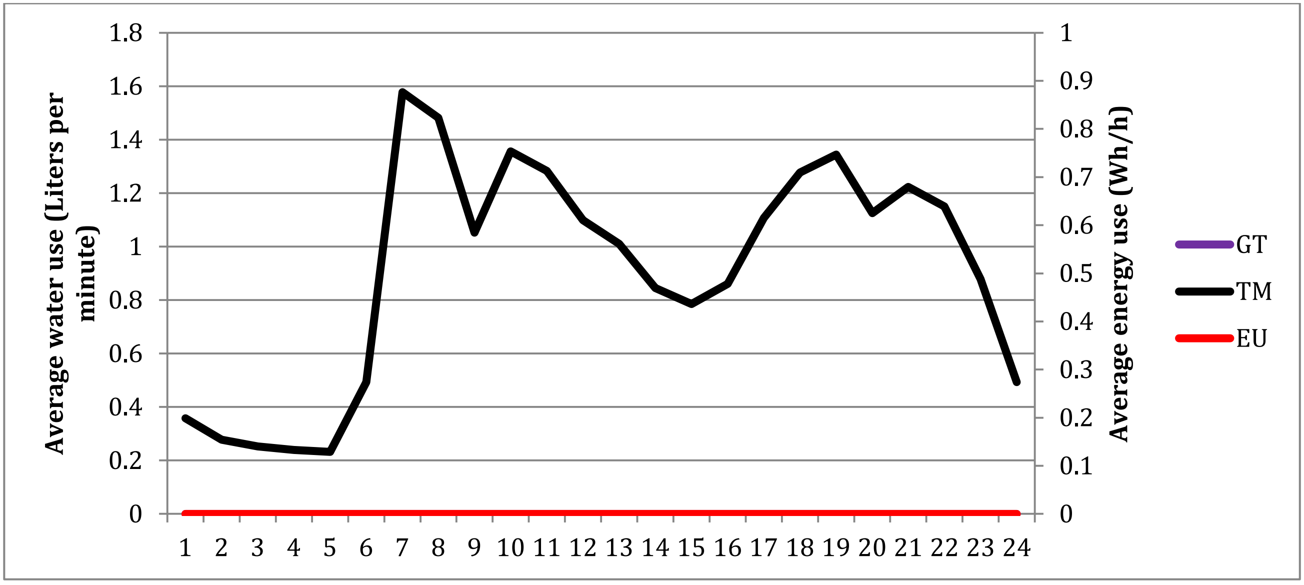



**Figure 60: hourly profiles (site 4)**

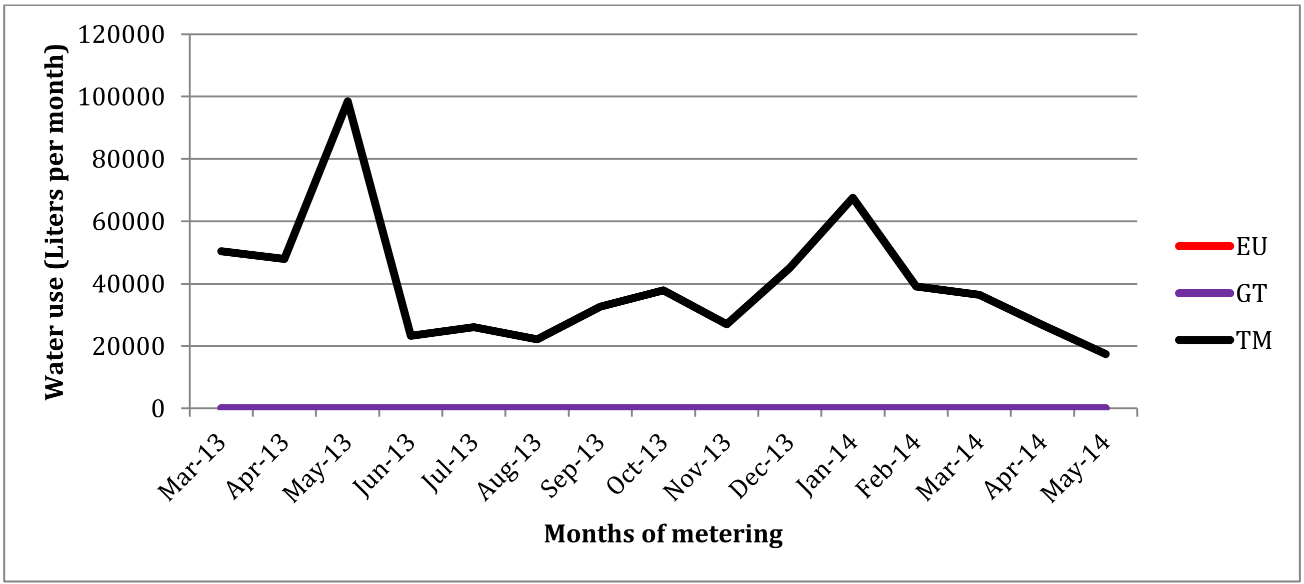



**Figure 61: Monthly profiles (site 4)**

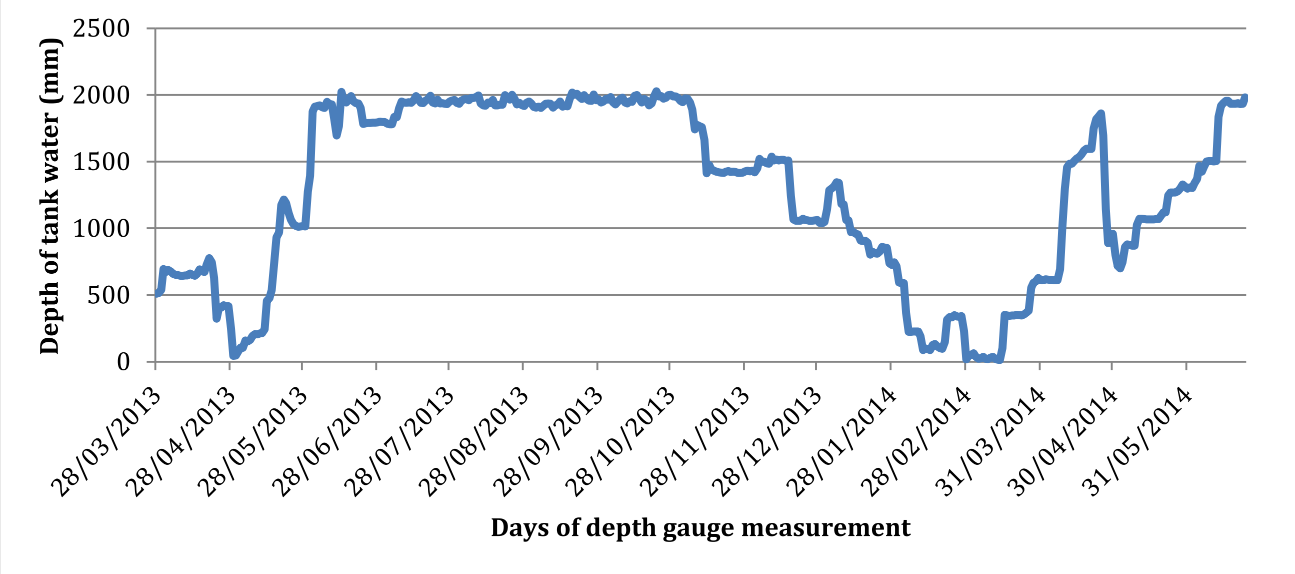



**Figure 62: Depth gauge data for site 4**

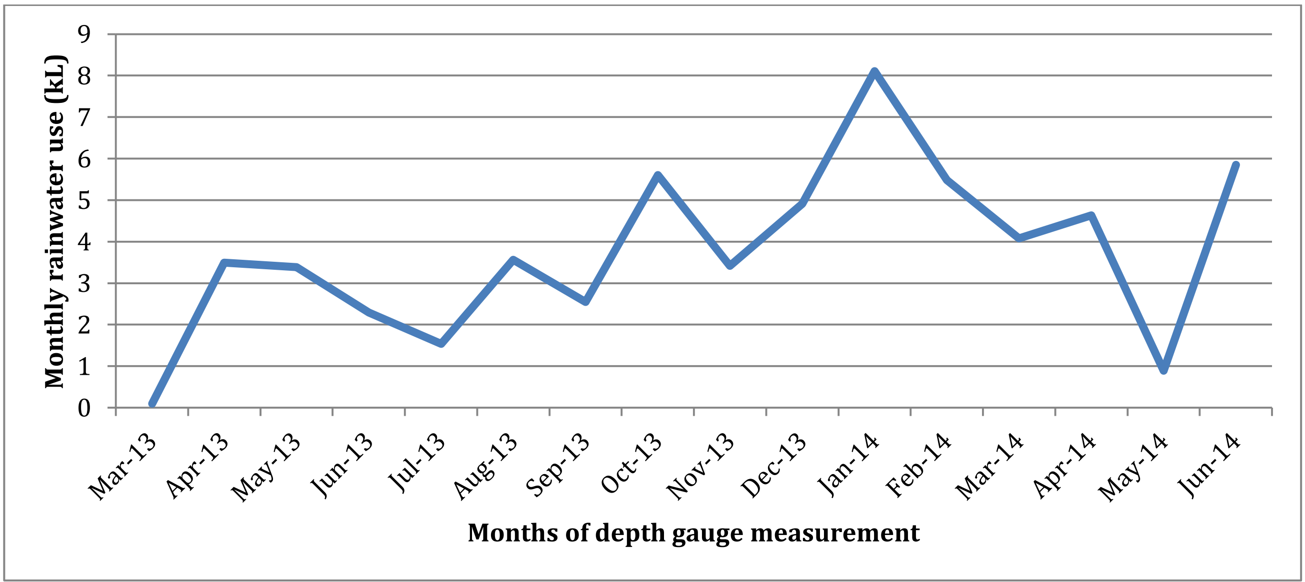



**Figure 63: Monthly rainwater use based on depth gauge measurement site 4**

### 5.3.5. Site 5

Site 5 has two rectangular tanks installed approximately 5 and 10 years ago. There is also a third tank which is used to top up the others when they run out of water. Each of the three tanks have a volume of 2 kLs. Rainwater is used for indoor and outdoor purposes and is connected to laundry, and two toilets. The pump type is submersible and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 30% of the roof area is connected; although the owner estimated that 50% of the roof area is connected to the tank. It was found that there are 6 downpipes on the house and three of these are connected to rainwater tanks.

As seen in Figure 65, the total mains meter was not functional until around August 2013. Mains water topup had a number of events in July and September 2013 and then over the summer at a number of instances. The total amount of mains water topup is still relatively small compared to rainwater use. As seen in Figure 64, the patterns of mains water use are rather different to rainwater use. The total mains water use follows a typical diurnal pattern, whilst the rainwater is being used during daylight hours; primarily in the middle of the day. This site has mains water top-up so when the tank runs dry it is filled up with mains water. The depth gauge data shows a typical pattern for the rainwater tank where it is consistently running dry and then subsequently filling up. The troughs in the water levels coincide with the automatic mains switch being activated.

Table 34: Summary variables for metering at site 5

| Summary variable | Total over the metering period | Total over the first 12 months* | Total over time when Total Mains meter was active* |
|---|---|---|---|
| Total tank water use (TORW) | 48.3 kL | 38.7 kL | 32.0 kL |
| Demand for tank water covered by mains water - switch (MWTU) | 6.0 kL | 3.8 kL | 5.4 kL |
| Total mains water (TM) | N/A | N/A | 59.3 kL |
| Rainwater used outdoors (GT) | 1.2 kL | 1.1 kL | 0.9 kL |
| Energy use (EU) | 46.4 kW | 36.6 kW | 29.8 kL |
| Total rainwater use (TORW-MWTU) | 42.3 kL | 34.9 kL | 26.6 kL |
| Volumetric reliability (TORW-MWTU)/( TM + TORW-MWTU) | N/A | N/A | 45% |
| Specific energy (EU/TORW-MWTU) | 1.5 kWh/kL | 1.48 kWh/kL | 1.53 kWh/kL |

***Note**: First twelve months: March 2013-February2014. Time when mains meter was active: August 2013-May 2014.

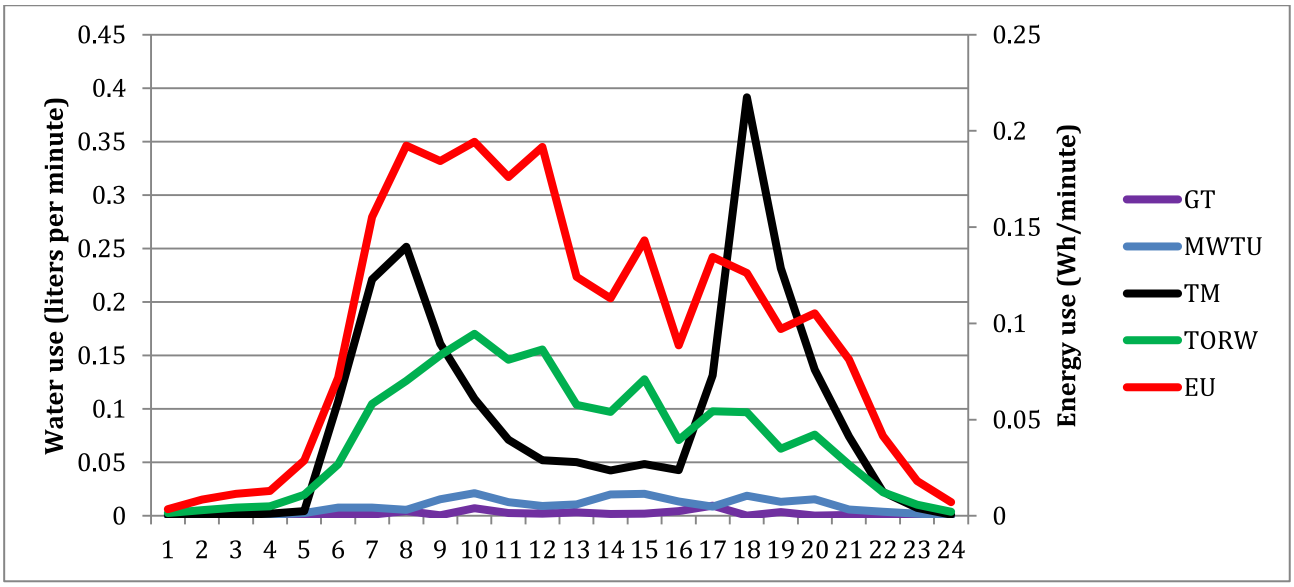



Figure 64: Hourly profiles - site 5

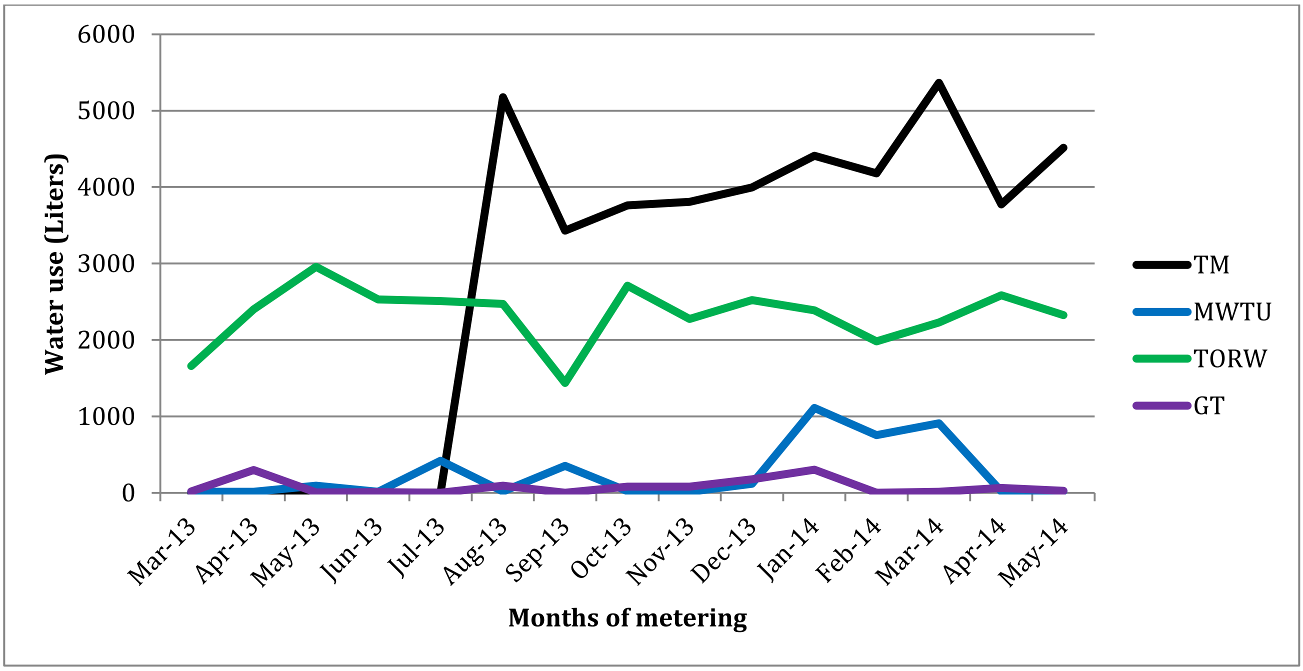



Figure 65: Monthly profiles - site 5

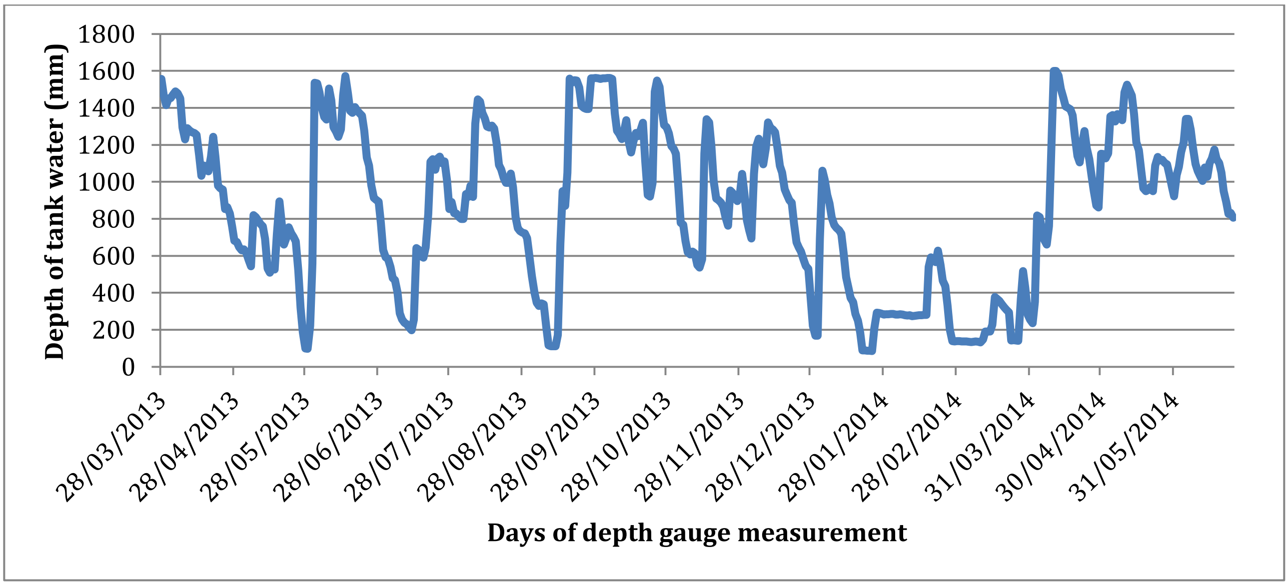



Figure 66: Depth gauge data - site 5

#### 5.3.6. Site 6

Site 6 has two rectangular tanks installed approximately 5 years ago. Both tanks have a volume of 3.5 kLs. Rainwater is used for indoor and outdoor purposes and the rainwater tanks are connected to laundry. There is an automatic mains switch. There are two garden taps, although one is not being used. The professionals who installed the metering equipment estimated that 30% of the roof area is connected; although the owner estimated that 100% of the roof area is connected to the tank. It was found that there are 8 downpipes on the house and two of these are connected to rainwater tanks. The hourly profile of water use in this site shows a typical diurnal pattern for the total mains water meter which also translates to a weaker diurnal pattern for rainwater use. MWTU here refers to the water flowing through the automatic switch, i.e. mains water being used at times when the water depth in the tank falls below a certain level. Unfortunately there is no depth gauge data for this site.

**Table 35: Summary information for metering data in site 6**

| Summary variable | Total over the metering period, i.e. 12 months* |
|---|---|
| Total rainwater use (TORW) | 38.6 kL |
| Automatic switch; mains water bypassing rainwater tank (MWTU) | 19.5 kL |
| Garden tap (GT) | 6.0 kL |
| Indoor usage of rainwater (TORW – GT) | 32.6 kL |
| Total mains use (TM)** | 85.0 kL |
| Volumetric reliability | 31% |
| Energy use (EU) | 38.7 kWh |
| Specific energy (EU/TORW) | 1.0 kWh/kL |

***Note**: June 2013-May 2014.

****Note**: There is missing data for TM. GT: 31/01/2014, 12:01:00 - 31/01/2014, 12:11:00

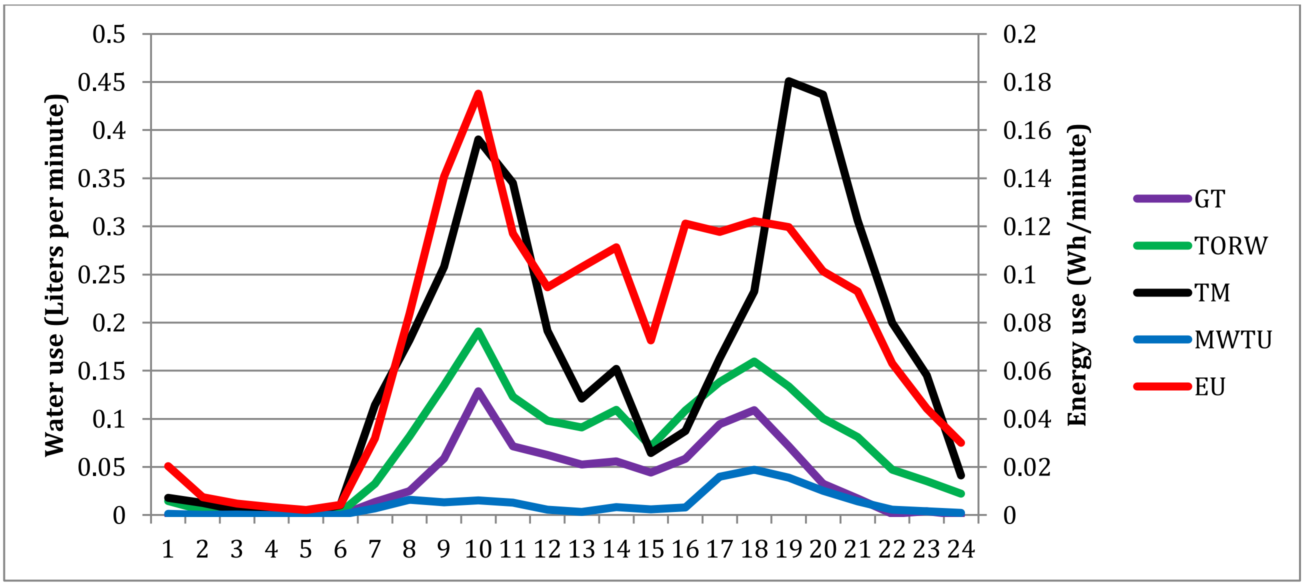



**Figure 67: Hourly profiles - site 6**

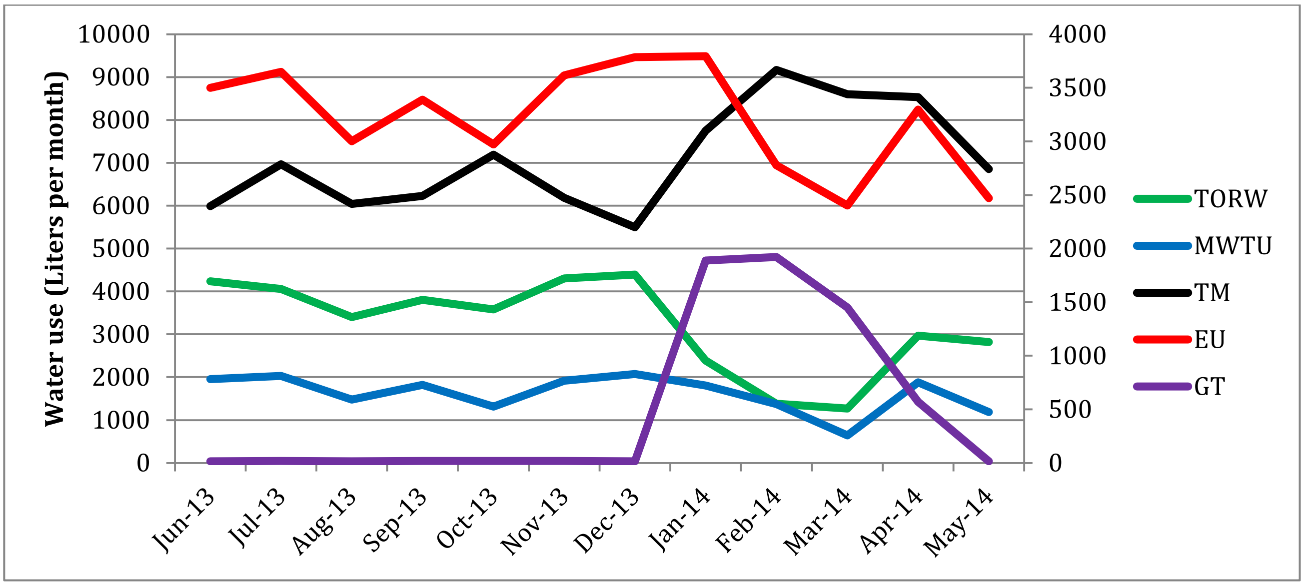



**Figure 68: Monthly profiles - site 6**

### 5.3.7. Site 7

Site 7 has a cylindrical tank installed approximately three years ago. The tank volume is approximately 5.6 kL. Rainwater is used for outdoor purposes only. The pump type is AL-KO JET802 and there is no automatic mains switch. The professionals who installed the metering equipment estimated that 30% of the roof area is connected. There is one downpipe connected to rainwater tanks. This site is interesting from the point of view of being primarily an outdoor purposes only tank. The hourly and monthly profiles reveal low rainwater use with a peak in the hot and dry summer months.

Estimates of rainwater use based on depth gauge measurements for the period of April 2013 – May 2014 are 3.5 kL and this aligns well with estimates based on flow meter data. Figure 71 shows clearly that rainwater has been used only at a limited number of times; primarily during the summer months.

**Table 36: Summary variables site 7**

| Summary variable | Total over the metering period* | Total over the first 12 months* |
|---|---|---|
| Garden tap (GT) | 6.6 kL | 6.5 kL |
| Energy use (EU) | 5.1 kW | 4.9 kW |
| Specific energy (EU/GT) | 0.8 kWh / kL | 0.8 kWh/kL |

*__Note__: The metering period: March 2013-April 2014. The first 12 months: March 2013-February 2014.

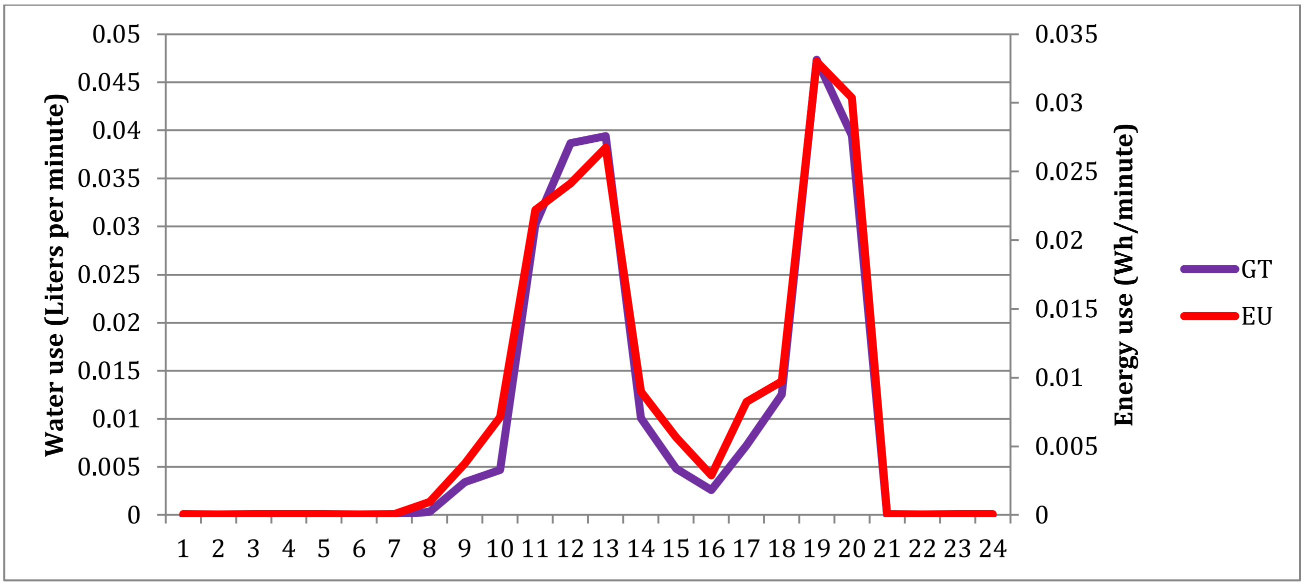



**Figure 69: Hourly profiles site 7**

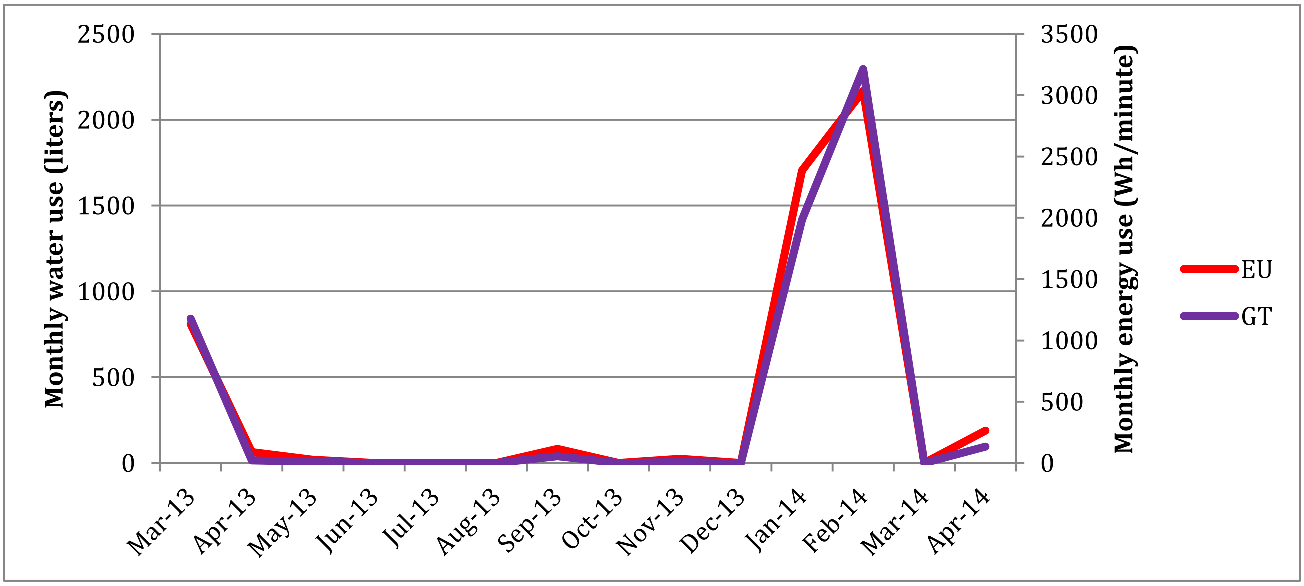



**Figure 70: Monthly profiles site 7**

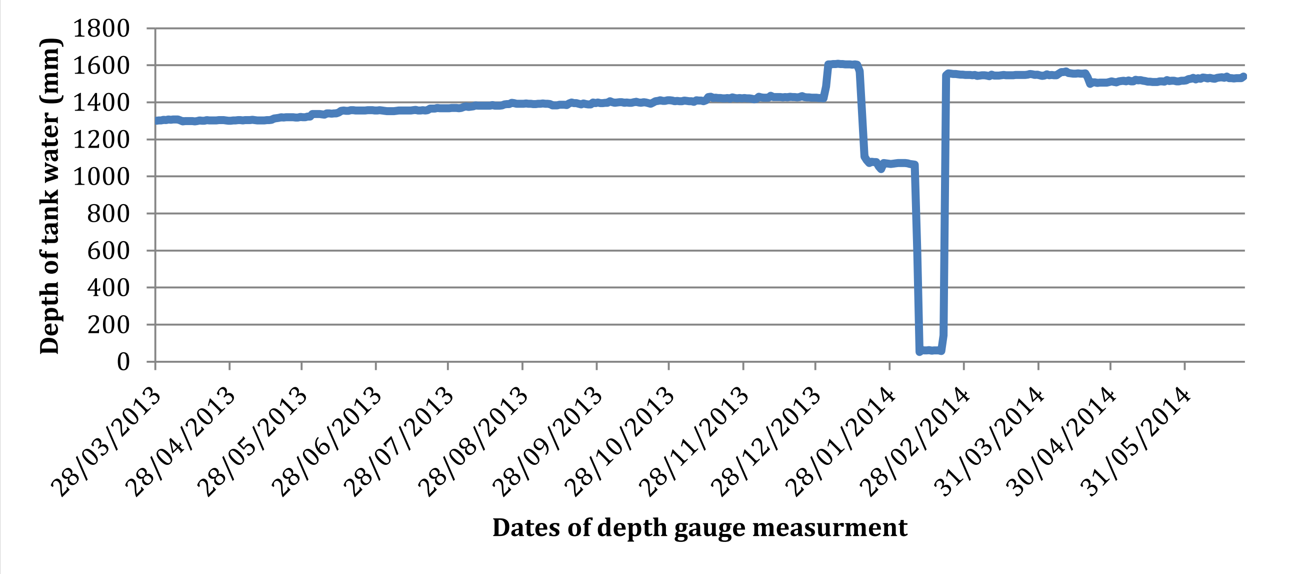



**Figure 71: Depth of tank water - site 7**

### 5.3.8. Site 8

Site 8 has one cylindrical tank installed approximately 2.5 years ago. The tank has a volume of approximately 3.7 kLs. Rainwater is used for indoor purposes and is connected to two toilets. The pump type is Universal UP-40DJZ037-1 and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 25% of the roof area is connected; although the owner estimated that 20% of the roof area is connected to the tank. It was found that there are 10 downpipes on the house and only one of these is connected to rainwater tank. The automatic switch in this site was broken and then repaired. The data is also not complete in this site due to various technical problems the metering was stopped on 22nd October 2013. This means that there was only 236 days of data. The metering had to be discontinued in this trial. This was because the switch had failed and the plumbers converted this to a simple 3 way valve.

It is noted that due to the fact that in this site rainwater is primarily used for indoor purposes, there is no strong seasonal element to the use. Therefore, it is possible to extrapolate these results to achieve a yearly estimate of rainwater use, based on a daily estimate of rainwater use. This site was metered for 236 days, and the average daily rainwater use was (if the switch had worked) was 42 liters. This would be extrapolated to an annual rainwater use of 15.3 kL. When the switch was not working, as in fact was the case, the amount of annual rainwater use would be 0.5 kL.

Figure 74 shows that the tank was about 60% full when metering started. The depth gauge data seems to indicate some legitimate rainwater use (i.e. rainwater as opposed to tank water demand being met by mains water from the switch) at a few times in this first month of metering, and this is backed up by the flow meter data. By middle of May the tank seems to have filled up – and subsequently the level never dropped below being nearly full. This time period is also indicated in the flow metering data by all tank water being met by the automatic mains switch.

In this site, the pump does not seem to have been activated when the automatic switch was operating. That is, until October when something odd seems to have happened and the pump registered regular energy use for a brief period of time on days in October 2013, including 11th October 2013 and in the days leading up to the pump and switch being turned off. During these short events on these days (10th and 11th October 2013), the estimated specific energy was 1.5 kWh/kL excluding standby energy use.

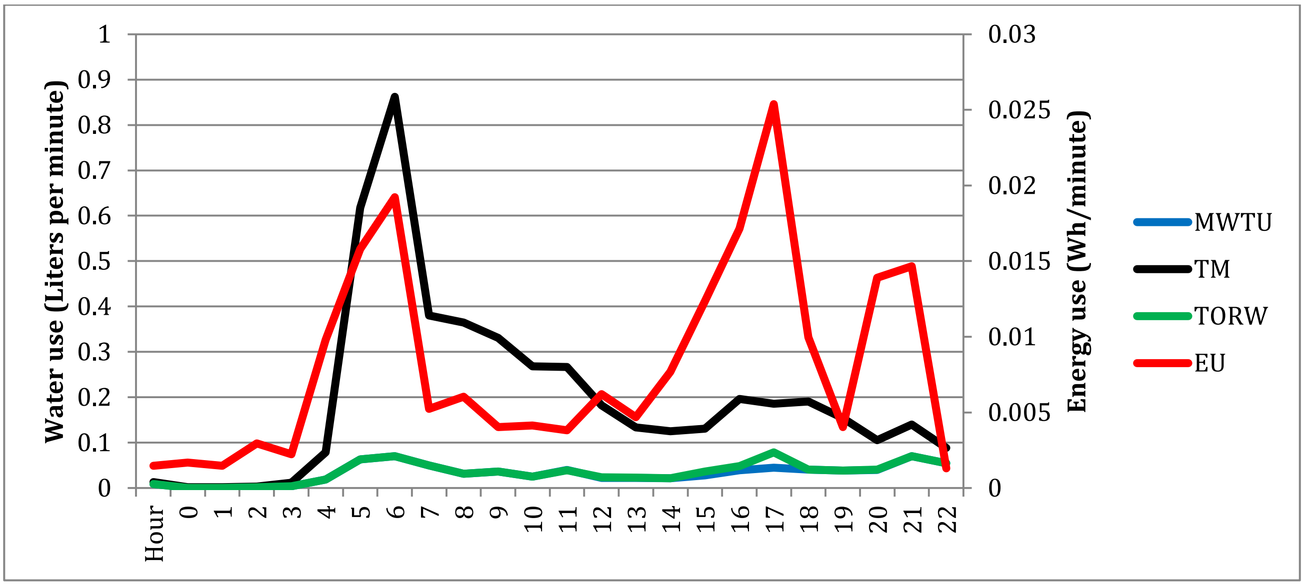



**Figure 72: Hourly profiles site 8**

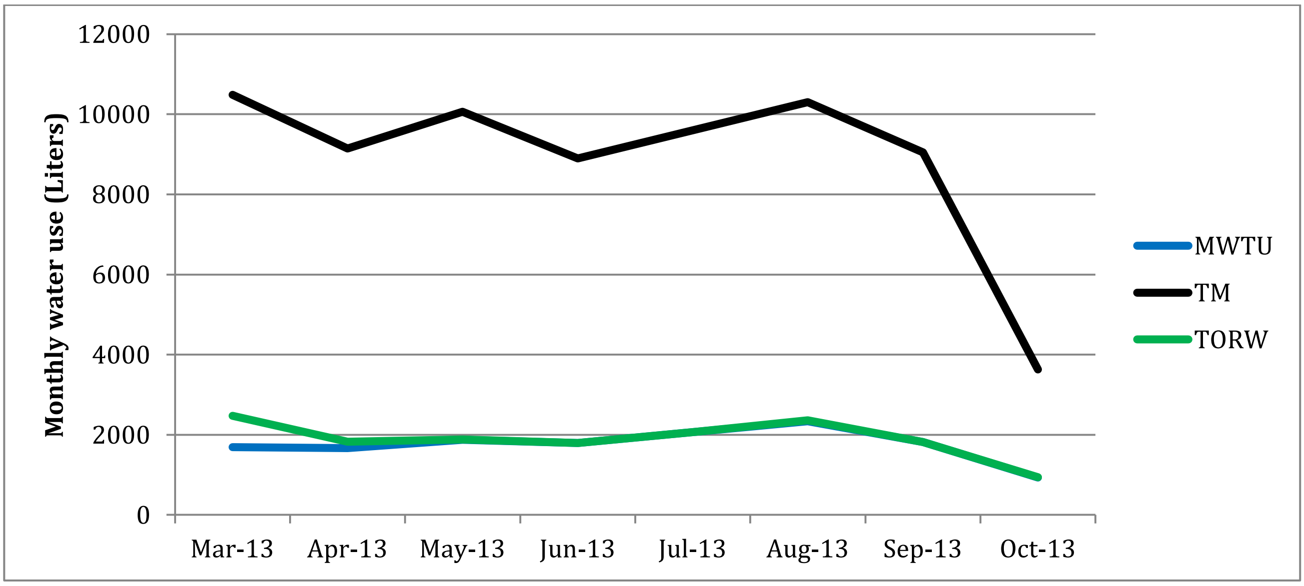



**Figure 73: Monthly profiles site 8**

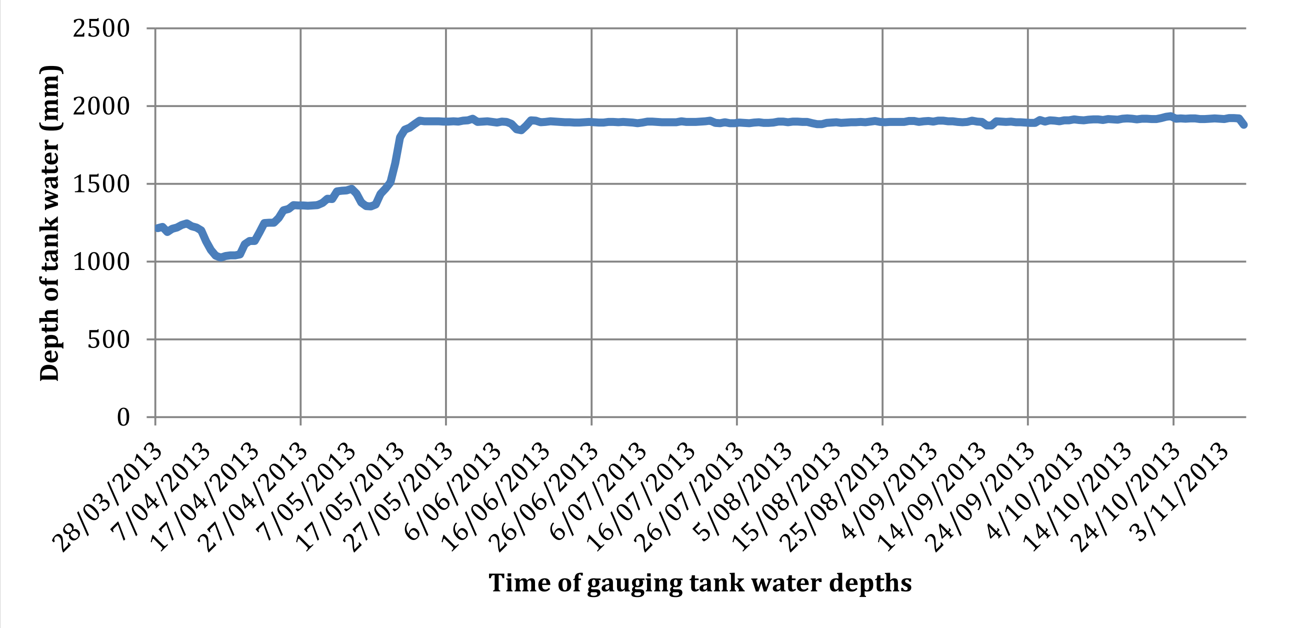



**Figure 74: Depth gauge levels site 8**

**Table 37: Summary information site 8**

| Summary variable | Total over the metering period* | Extrapolated values to 12 months |
|---|---|---|
| Total mains use (TM) | 79.3 kL | 105.7 kL |
| Tank water used (TORW) | 15.2 kL | 20.2 kL |
| Automatic mains switch (MWTU) | 14.2 kL | 18.9 kL |
| Standby energy use (selected EU events) | 0.68 kWh | 1.1 kWh |
| Energy use extrapolated based on standby energy and specific energy*** | 16.7 kWh | 24.0 kWh |
| Specific energy (excl. standby)** | 1.1 kWh/kL | 1.1 kWh/kL |
| Specific energy (incl standby)** | 1.2 kWh/kL | 1.2 kWh/kL |
| Total rainwater use (TORW-MWTU) | 1.0 kL | 1.3 kL |
| Total possible rainwater use (TORW) | 15.2 kL | 20.2 kL |

***Note**: March 2013-October 2013. 236 days.

****Note**: This specific energy estimate is based on the best available data which unfortunately is only a handful of events when the pump and switch appear to have been operating in an adequate manner. This estimate excludes standby energy.

*****Note**: This estimate takes into account a standby energy use of 2.9 Wh per day (1.1 kWh per year) as well as a specific energy of 1.5 kWh/kL based on individual water use events when the pump and switch appeared to be working.

### 5.3.9. Site 9

Site 9 has one rectangular tank installed approximately 3 years ago. The tank has a volume of approximately 1.5 kLs. Rainwater is used for indoor purposes and is connected to a toilet. One garden tap is connected. The pump type is Davey HP45-05 and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 40% of the roof area is connected. It was found that there are 4 downpipes on the house and only one of these is connected to rainwater tank. The automatic switch in this site was broken and then turned off. The total tank water usage in this site is relatively high over the metering period with 39.9 kL used for indoor purposes and 7.1 kL used for outdoor purposes. However due to the faulty automatic switch, most of this water was supplied from the mains water supply.

**Table 38: Summary variables for site 9**

| Summary variable | Total over the metering period* | Total over the first 12 months** |
|---|---|---|
| Total tank water used for indoor purposes (TORW) | 39.9 kL | 33.6 kL |
| Automatic switch (MWTU) | 36.8 kL | 33.4 kL |
| Total rainwater used for indoor purposes (TORW-MWTU) | 3.1 kL | 0.2 kL |
| Garden tap (GT) | 7.1 kL | 7.1 kL |
| Total mains use (TM) | 169.8 kL | 144.6 kL |
| Energy use (EU) | 10.4 kWh | 5.3 kWh |
| Total rainwater use (GT + TORW – MWTU) | 10.2 kL | **7.3** kL |
| Total potential savings if switch was functional (GT + TORW) | 47.0 kL | **40.7** kL |
| Specific energy (EU / GT + TORW - MWTU) | 1.0 kWh/kL | 0.7 kWh/kL |

***Note**: April 2013-May 2014.

****Note**: April 2013 – March 2014.

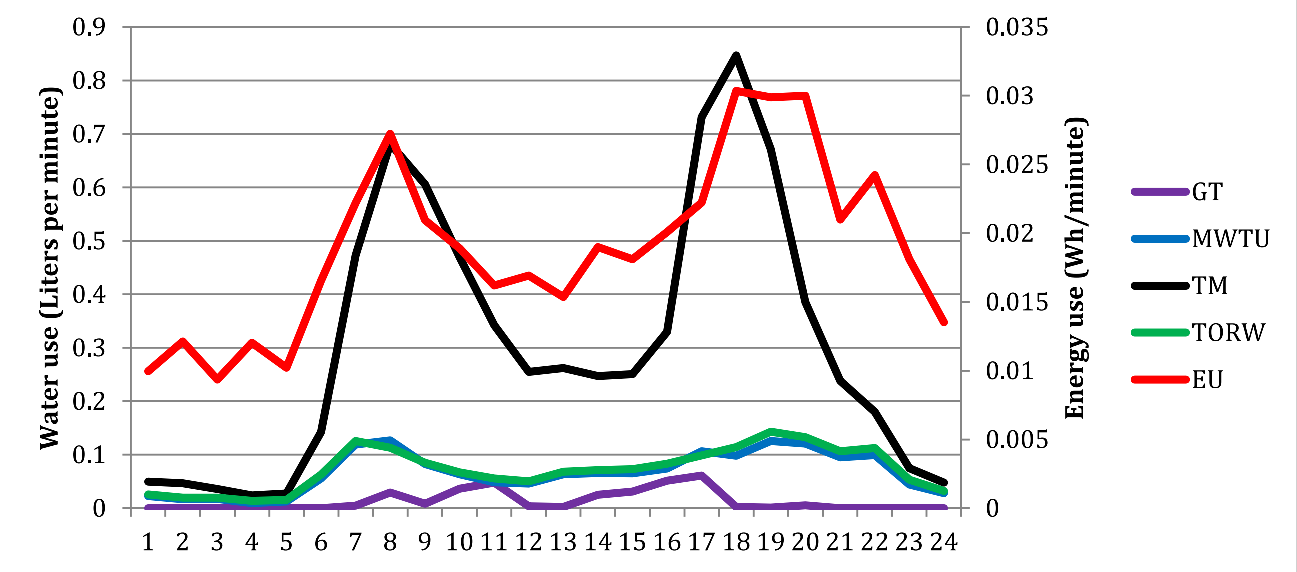
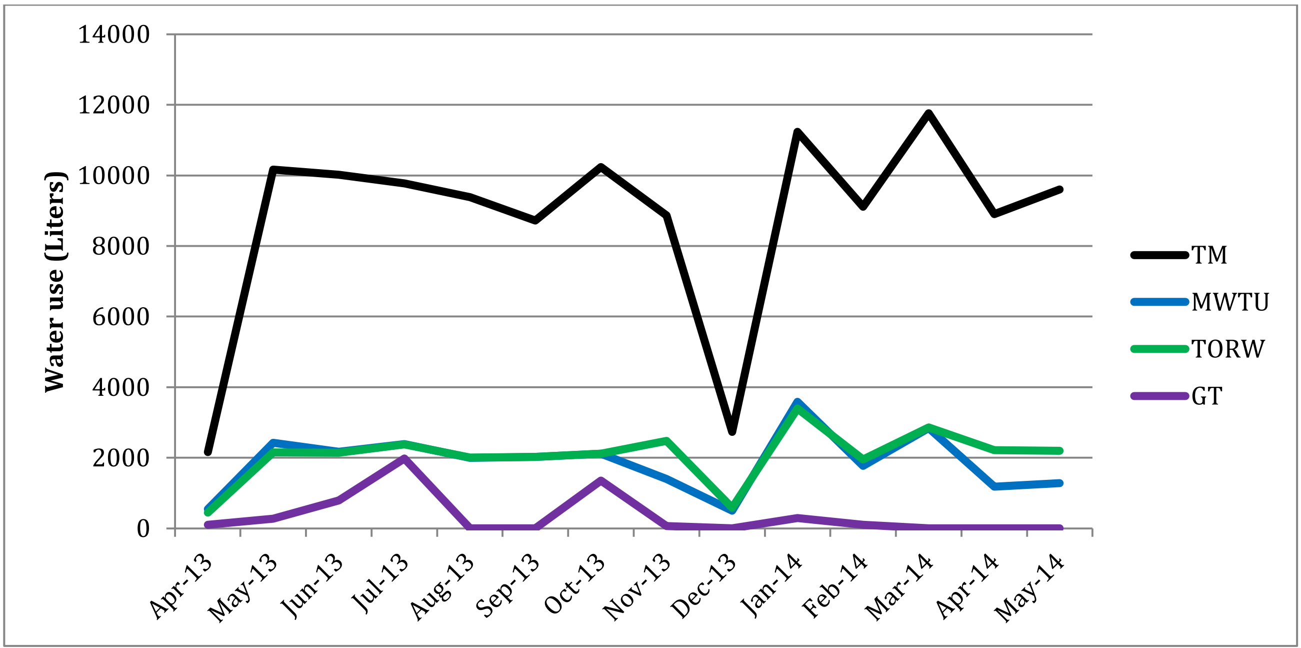



**Figure 75: Hourly profiles site 9**

**Table 39: Monthly profiles site 9**




### 5.3.10. Site 10

Site 10 has one rectangular tank installed approximately 3 years ago. The tank volume is approximately 1.5 kLs. Rainwater is used for indoor purposes and is connected to a toilet. One garden tap is connected. The pump type is Davey HP45-05 and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 50% of the roof area is connected. It was found that there are 4 downpipes on the house and two of these are connected to rainwater tank. The automatic switch in this site was broken and then turned off.

**Table 40: Summary variables site 10**

| Summary variable | Total over the metering period* | Total over the 12 months starting* | Total over the time when mains meter was monitored* |
|---|---|---|---|
| Total tank water used (TORW) | 30.9 kL | 25.6 kL | 21.0 kL |
| Automatic switch (MWTU) | 28.6 kL | 23.2 kL | 18.7 kL |
| Garden tap (GT) | 11.5 kL | 10.0 kL | 8.4 kL |
| Total mains use (TM) | 166.6 kL** | 133.2 kL** | 111.0 kL |
| Energy use (EU) | 26.9 kWh | 26.5 kWh | 19.4 kWh |
| Total rainwater use (TORW + GT – MWTU) | 13.9 kL | 12.3 kL | 10.8 kL |
| Total rainwater use potential (TORW + GT) | 42.4 kL | 35.6 kL | 29.4 kL |
| Specific energy (EU / TORW + GT – MWTU) | 1.9 kWh/kL | 2.2 kWh/kL | 1.8 kWh/kL |

***Note**: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014. Time when mains meter was monitored: August 2013-May 2014.

****Note**: Extrapolated based on average monthly use.

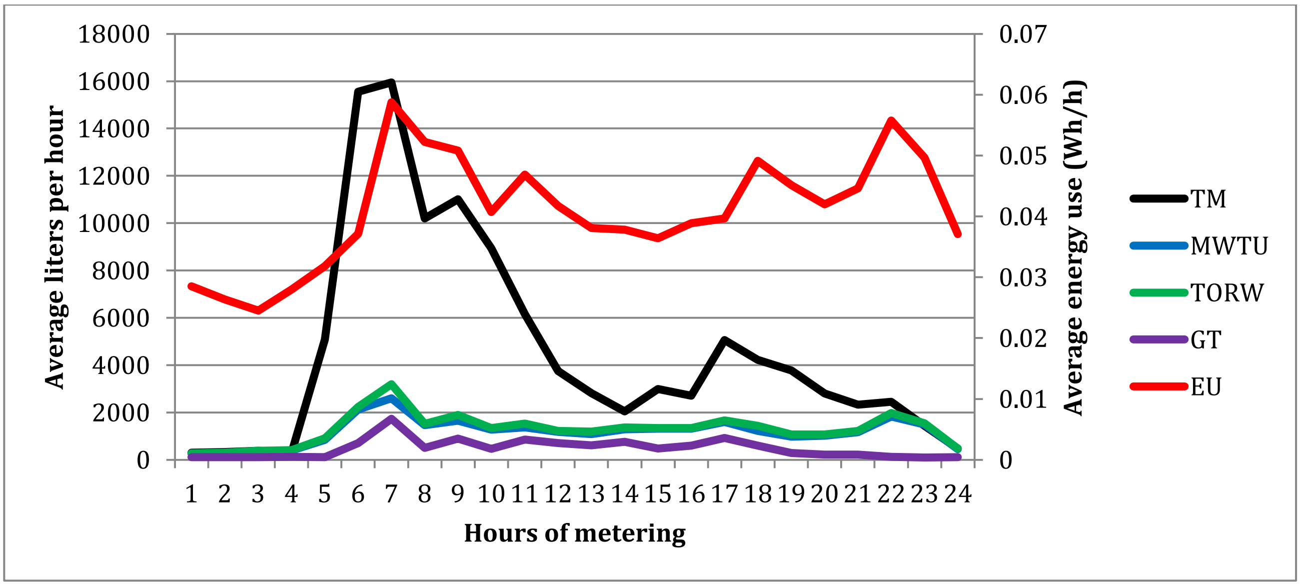



**Figure 76: Hourly profiles site 10**

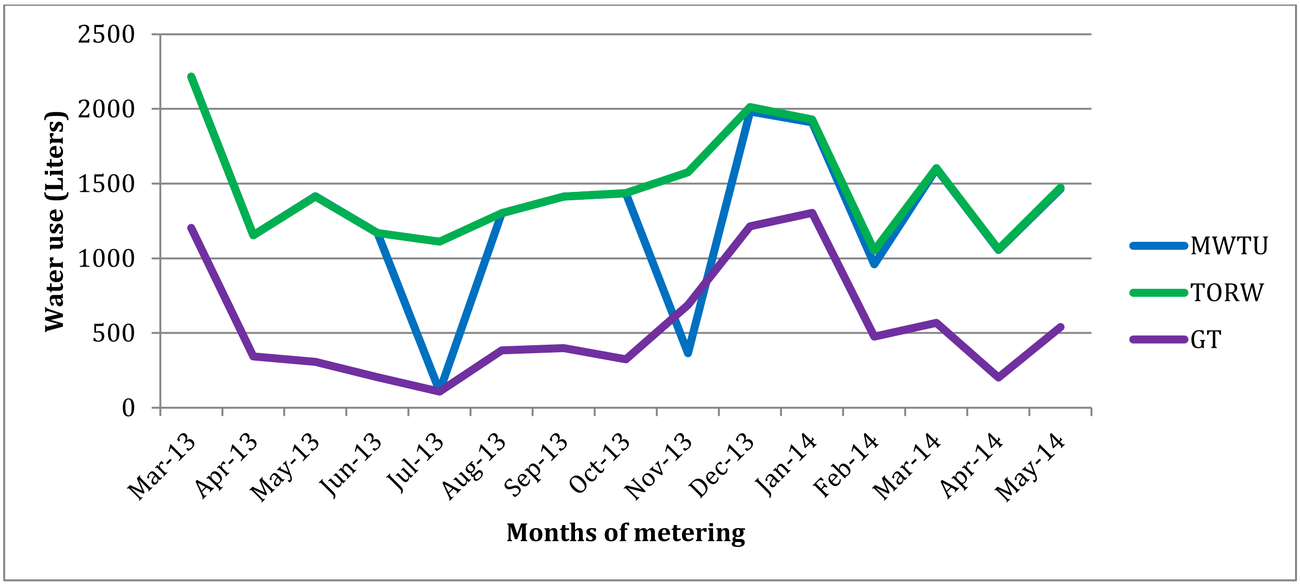



**Figure 77: Monthly profiles site 10**

### 5.3.11. Site 11

Site 11 has one rectangular tank installed approximately 3 years ago. The tank volume is 5 kLs. Rainwater is used for outdoor and indoor purposes and is connected to a 2 toilets and laundry. Two garden taps are connected. The pump type is Davey HP45-05 and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 30% of the roof area is connected; whilst the owner estimated that 40% of the roof is connected. It was found that there are 5 downpipes on the house and two of these are connected to rainwater tank.

Inspection of the metering data reveals the following insights:

- Up until November 2013, when tank water was being used, the mains switch was automatically activated whenever tank water was used and so during this time mains water was used to meet tank water demand. After this time, this was not the case. This also shows up as a decrease in the depth of water in the depth gauge data (see Figure 80)
- The pump is used whenever tank water is being used.
- Garden tap water is included in the total rainwater being used.
- The total mains flows that were metered are suspiciously low (see Figure 79) and are therefore disregarded for further purposes.
- Most of the rainwater use seems to have occurred in November-December 2013 when for some reason the automatic switch was not operating. It was not reported by plumbers that the automatic switch was faulty in this site, but it does seem like there have been some problems.

The total savings from rainwater use, as shown in Table 41, are calculated as the total rainwater used minus the mains water flowing through the automatic switch. This is in acknowledgment that the total metered tank water use volume includes the garden tap use volume. The automatic switch in this site is not operational and it appears the pump was turned off in January 2014. This leaves the total rainwater use at a mere 14 kL, but the potential water savings in this site however are much higher, at approximately 63 kL for the 12 months starting when metering started.

**Table 41: Summary variables site 11**

| Summary variable | Total over the metering period* | Total over the 12 months starting* | Total over the time when energy use was monitored* |
|---|---|---|---|
| Total tank water use (TORW) | 69.7 kL | 61.2 kL | 51.2 kL |
| Automatic switch use (MWTU) | 58.3 kL | 49.7 kL | 40.2 kL |
| Garden tap use (GT) | 2.5 kL | 2.5 kL | 2.0 kL |
| Energy use (EU) | N/A | N/A | 37.8 kWh |
| Total rainwater use (TORW + GT – MWTU) | 14.0 kL | 14.0 kL | 12.9 kL |
| Specific energy (EU / TORW + GT - MWTU) | N/A | N/A | 2.9 kWh/kL |

***Note**: Metering period: March 2013 – May 2014. First 12 months: March 2013 – February 2014. Time when energy use was monitored: March 2013 – December 2013.

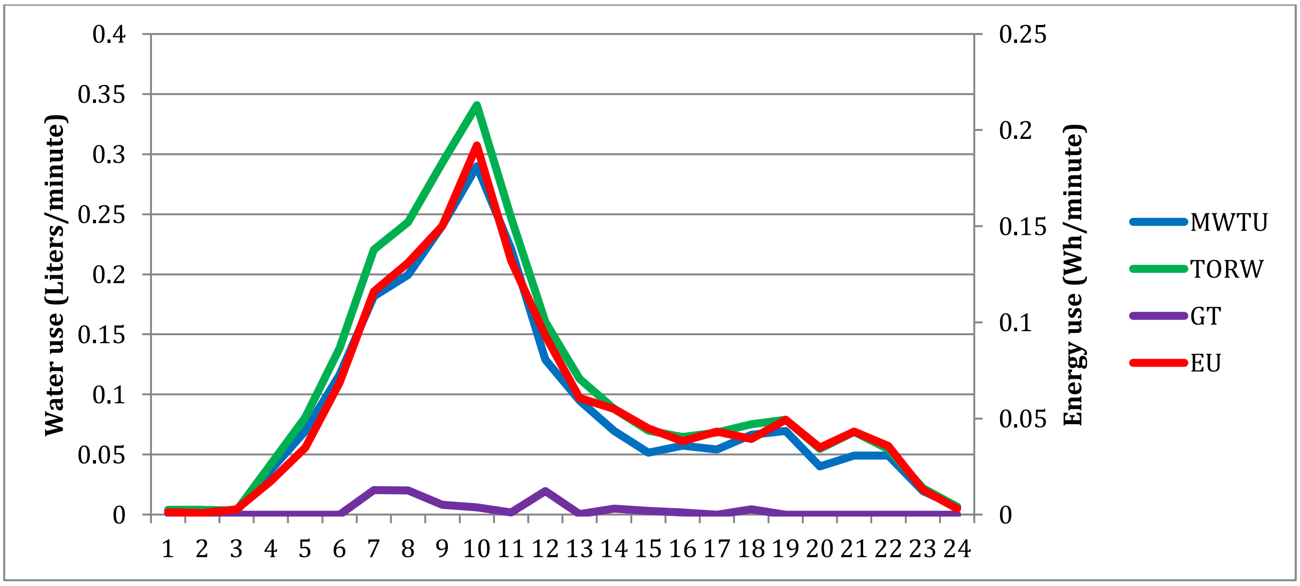



**Figure 78: Hourly profiles site 11**

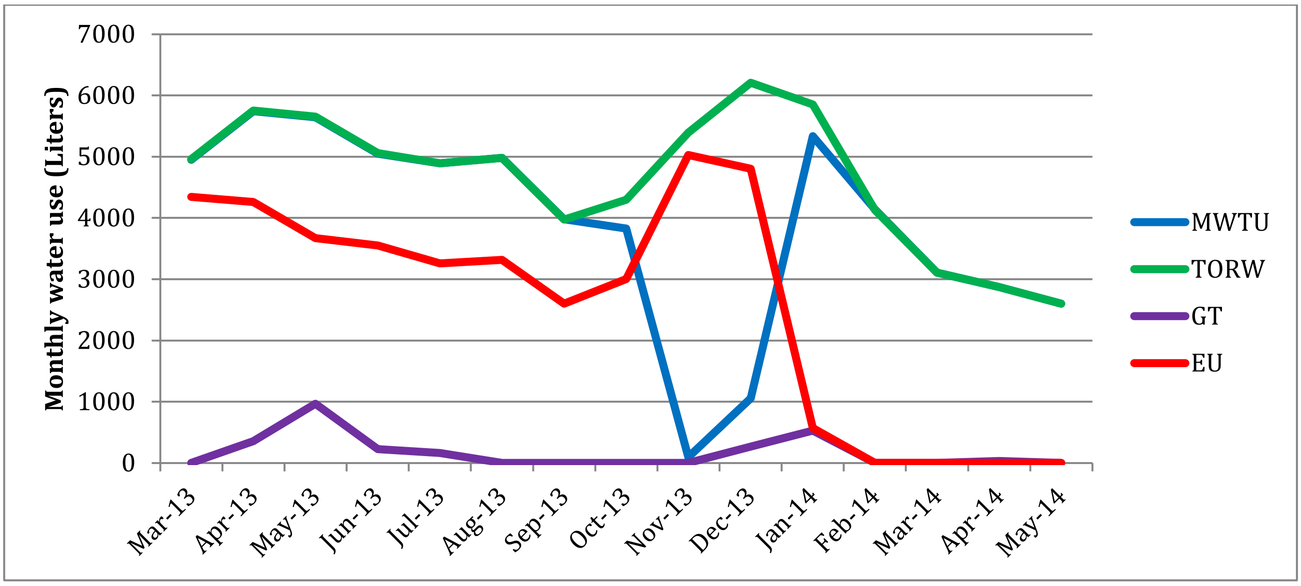



**Figure 79: Monthly profiles site 11**

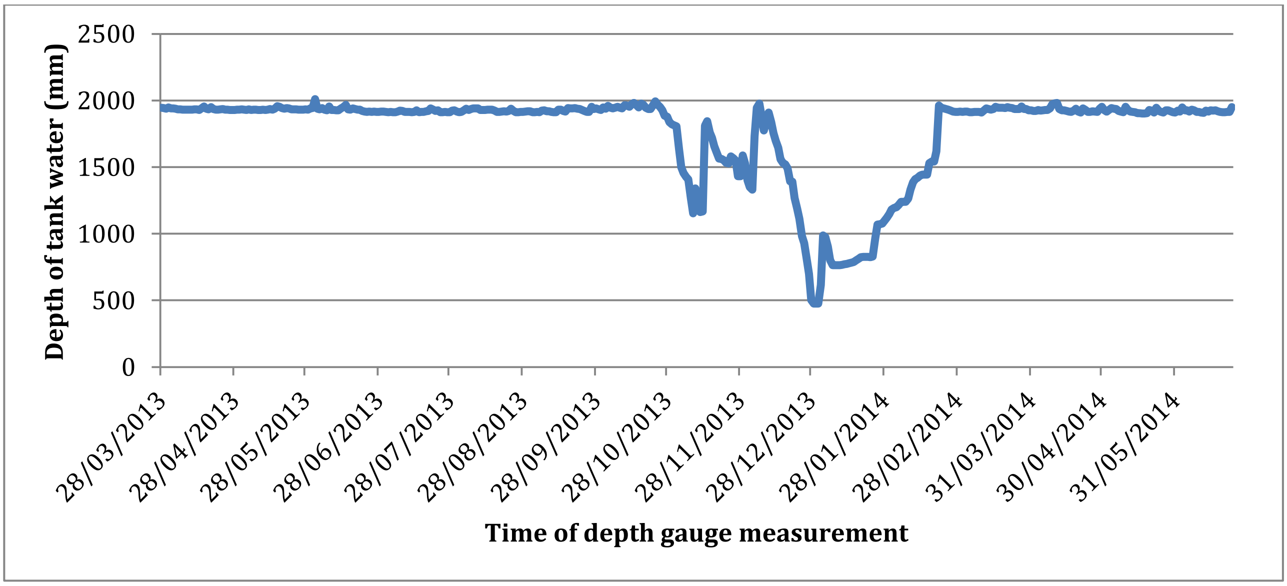



**Figure 80: Depth gauge data site 11**

### 5.3.12. Site 12

Site 12 has one cylindrical tank installed approximately 5 years ago. The tank volume is 5 kLs. Rainwater is used for outdoor and indoor purposes: garden, pool and toilet. One garden tap is connected but the householder noted that only a very marginal amount of outdoor use occurred during the metering period. The pump type is AL-KO WW802 and there is no automatic mains switch. During the metering period, the pump had to be removed and repaired. During this time the tank was offline for a day or two. The professionals who installed the metering equipment estimated that 30% of the roof area is connected. Unfortunately this site only started being metered in August 2013.

The depth gauge measurement data can again be used for estimating water use, by estimating outflows from the tank (indicated by a reduction in the water level). Again a difference is found between the estimated water use based on metering and that which is based on flow meters. Depth gauge metering estimates a higher water use. It is quite likely that flow meters do not pick up water use that is not pressurized. The seasonal nature of the water use shows that it is likely that a considerable amount of the water was used for gardening.

**Table 42: Summary variables site 12**

| Summary variable | Total over the metering period: 10 months* | Extrapolated to 12 months** |
|---|---|---|
| Total rainwater used (TORW) | 14.4 kL | 14.6 kL |
| Garden tap (GT) | 0 kL | 0 kL |
| Total mains (TM) | 167.9 kL | 214.3 kL |
| Volumetric reliability | 8% | 6% |
| Energy use (EU)* | 11.5 kWh | 11.6 kWh |
| Specific energy (EU / TORW+GT) | 0.8 kWh/kL | 0.8 kWh/kL |

***Note**: Time period: August 2013-May 2014.

****Note**: Extrapolation based on two month moving averages.

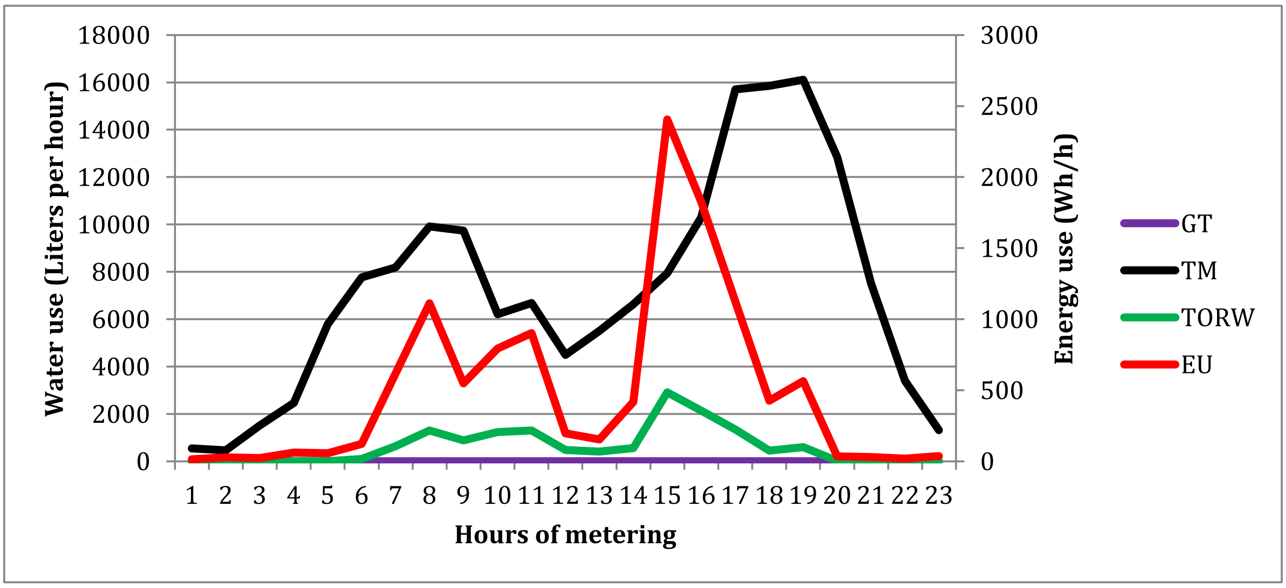



**Figure 81: Hourly profiles site 12**

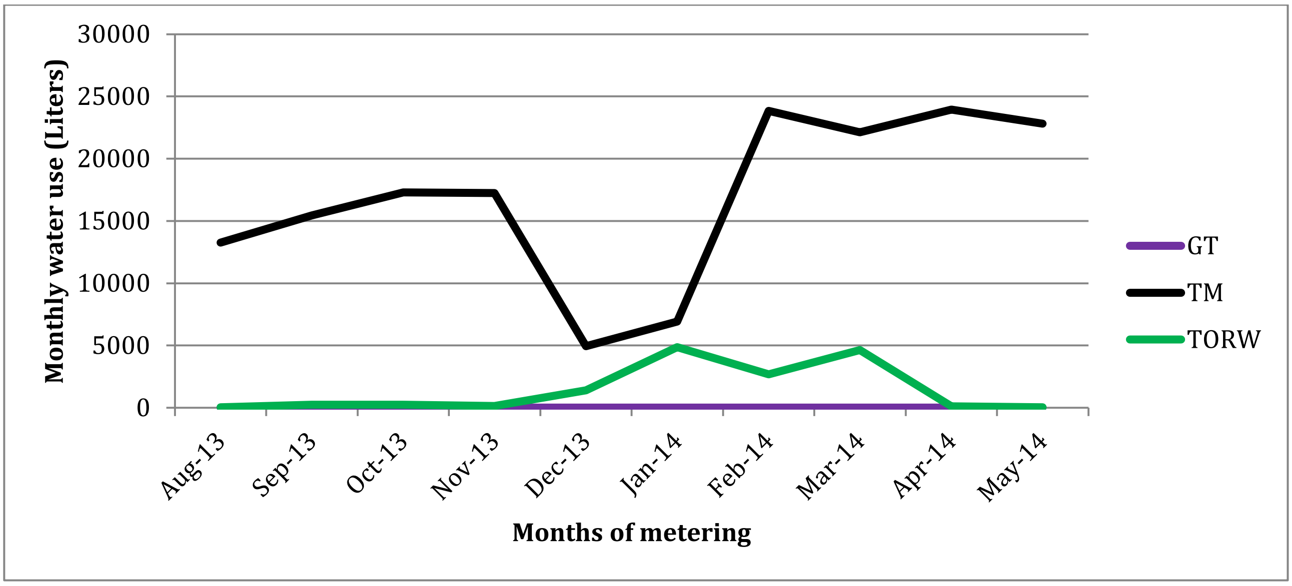



Figure 82: Monthly profiles site 12

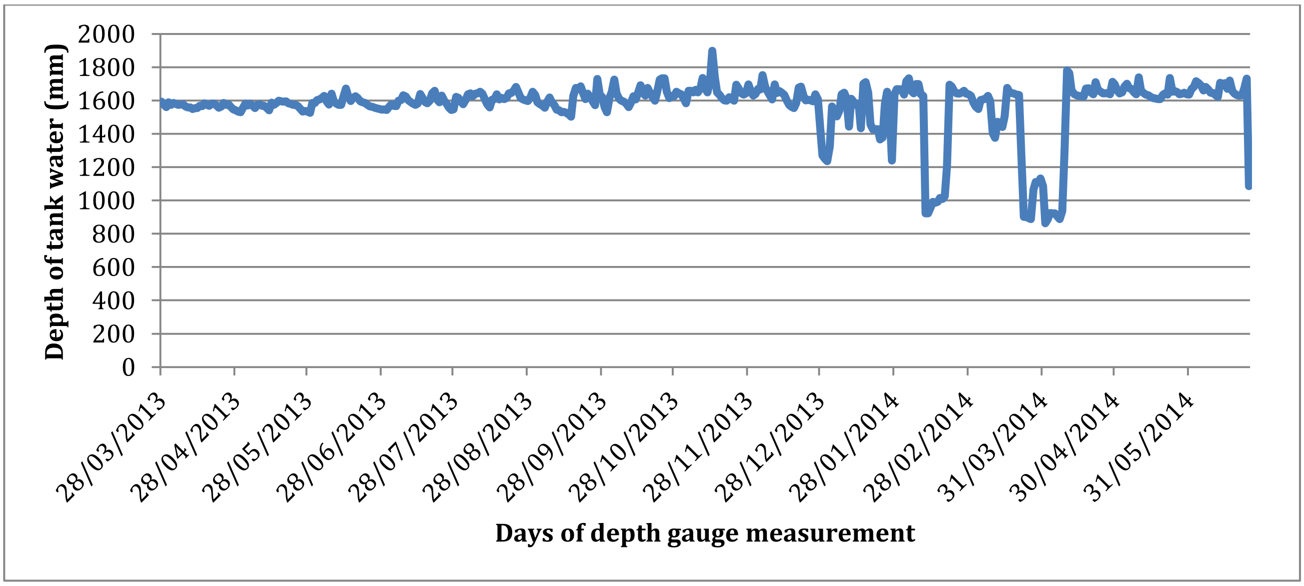



Figure 83: Depth gauge measurements site 12

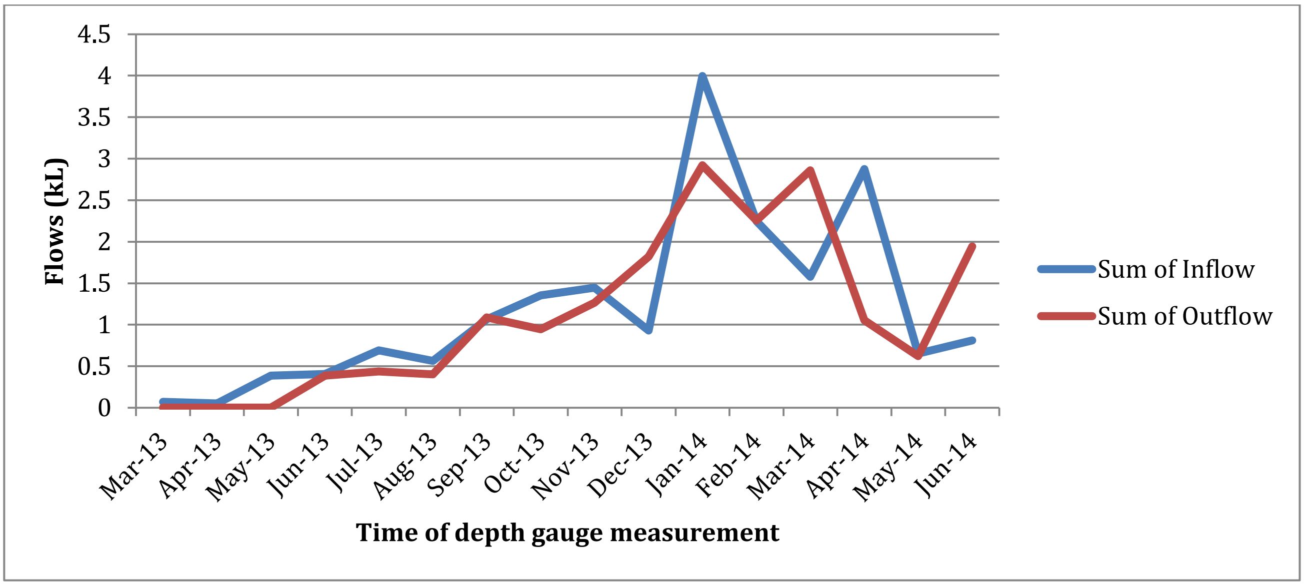



**Figure 84: Estimates of inflows and outflows based on depth gauge measurement site 12**

#### 5.3.13. Site 13

The site 13 rain water storage system consists of 3 large plastic water tanks. The largest has a capacity of 7 kL with the others reducing in size (4.5 kL and 2.25 kL). The combined capacity of the 3 tanks is in the order of 13.75 kL. All rainwater harvested from the house roof is channeled via 6 inch underground (wet-system) storm-water pipe to the large tank. When the 7 kL tank is full it overflows into the 4.5 kL tank, and then to the small 2.25 kL tank. Rain water from the garage roof is fed into the 4,500 kL, with a small amount fed directly into the small tank. No provision is currently made to direct water in the 6 inch underground transfer pipe to the pump. Drain caps are provided at low points for flushing the underground pipes. Each of the three tanks is plumbed to a common feed pipe supplying a pressure pump. By manipulating stop cocks on each of the pipes, water can be transferred from one tank to another using gravity – at least until the water levels across the tanks is equal. Transfer can also be achieved by pressure pump by connecting a hose to a tap on the high-pressure side and feeding the other end into the target tank. Fine mesh filters are positioned around the house at each downpipe to prevent leaves and other large objects entering the system. Mesh is also used at each tank inlet as a secondary filter, and a third in-line filter is positioned immediately before the pump. The primary reason for installing the storage system was to provide water to the garden during summer months when severe water restrictions were in place at the time. During the months when rainwater is plentiful, the storage water is also directed to supply two toilet cisterns for flushing. A three-way valve (with no overlap) is used for directing water from either domestic supply or rainwater storage tank. There is no automatic switch or mains water top-up in this site. No depth gauge data has so far been provided for this site.

Based on the data shown in Figure 85 and Figure 86 it is evident that whilst the main purpose for installing the tanks was for gardening; the most rainwater use occurs inside the house. The total rainwater use over the 12 months is 46.7 kL and the specific energy for this time period is 1.7 kWh/kL, which is within the normal range.

Table 43: Summary variables site 13

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering* |
|---|---|---|
| Total rainwater used (TORW) | 54.4 kL | 46.7 kL |
| Garden tap (GT) | 1.2 kL | 1.1 kL |
| Total mains (TM) | 86.9 kL | 64.8 kL |
| Volumetric reliability | 38% | 42% |
| Energy use (EU) | 98.7 kWh | 77.1 kWh |
| Specific energy (EU/TORW) | 1.8 kWh/kL | 1.7 kWh/kL |

***Note**: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014.

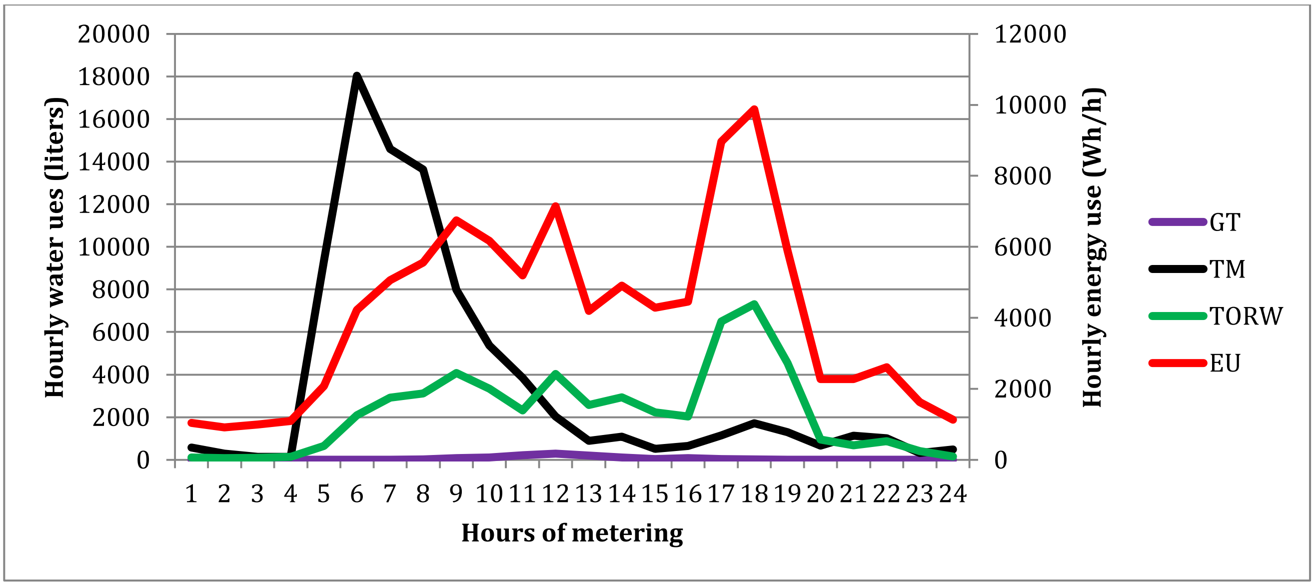



Figure 85: Hourly profiles site 13

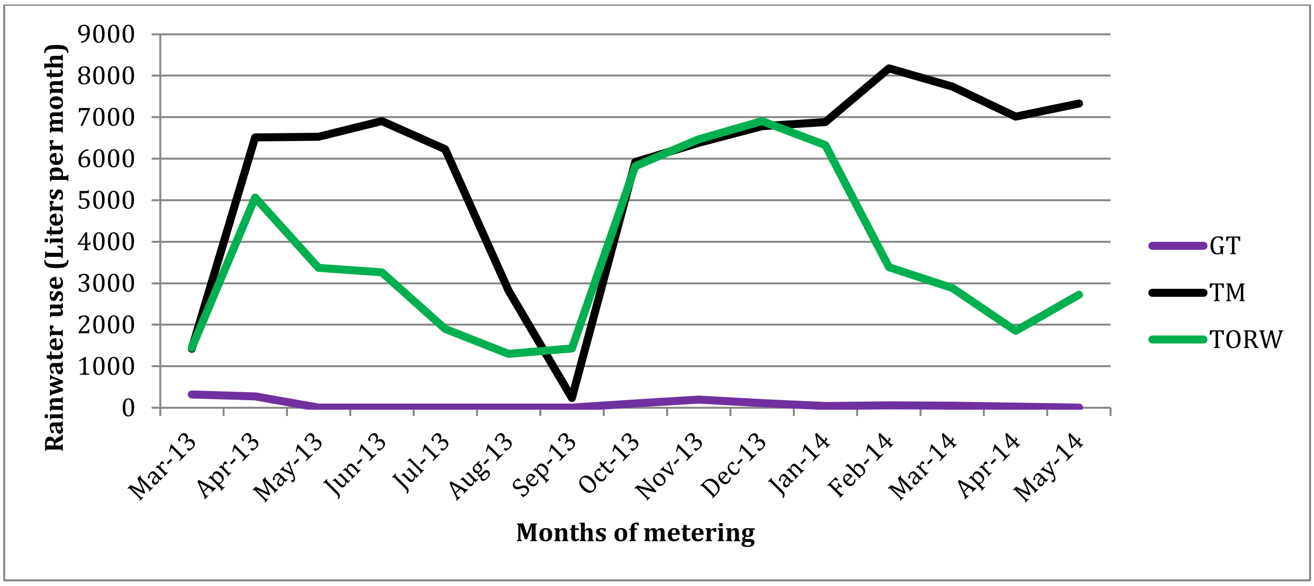



**Figure 86: Monthly profiles site 13**

### 5.3.14. Site 14

Site 14 has two cylindrical tanks installed. One 2.25 kL tank installed 4 years ago and one 0.6 kL tank installed 11 years ago. Rainwater is used for outdoor purposes only: garden, car, general house maintenance e.g. cleaning weatherboards. Only one garden tap is connected. The pump type is ClayTech and there is no automatic mains switch. The professionals who installed the metering equipment estimated that 100% of the back shed roof area is connected. As can be seen in Figure 88 and Figure 87, there is no garden tap or rainwater usage being registered at this site. To double check and get an alternative estimate of rainwater use, depth gauge data can be used as per Figure 89. Depth gauge data was used to estimate rainwater use as per Figure 90.

**Table 44: Summary variables site 14***

| Summary variable | Total for the metering period | Total for the first 12 months of metering |
|---|---|---|
| Total rainwater used (TORW) | 6.2 kL | 5.1 kL |
| Total rainwater used (est. based on depth gauge data) | 6.4 kL | 4.9 kL |
| Total mains – flow meter estimate (TM) | 67.6 kL | 52.9 kL |
| Volumetric reliability (TORW/TM+TORW) | 6.7% | 8.8% |

***Note**: The electricity meter was not operational in this site.

****Note**: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014.

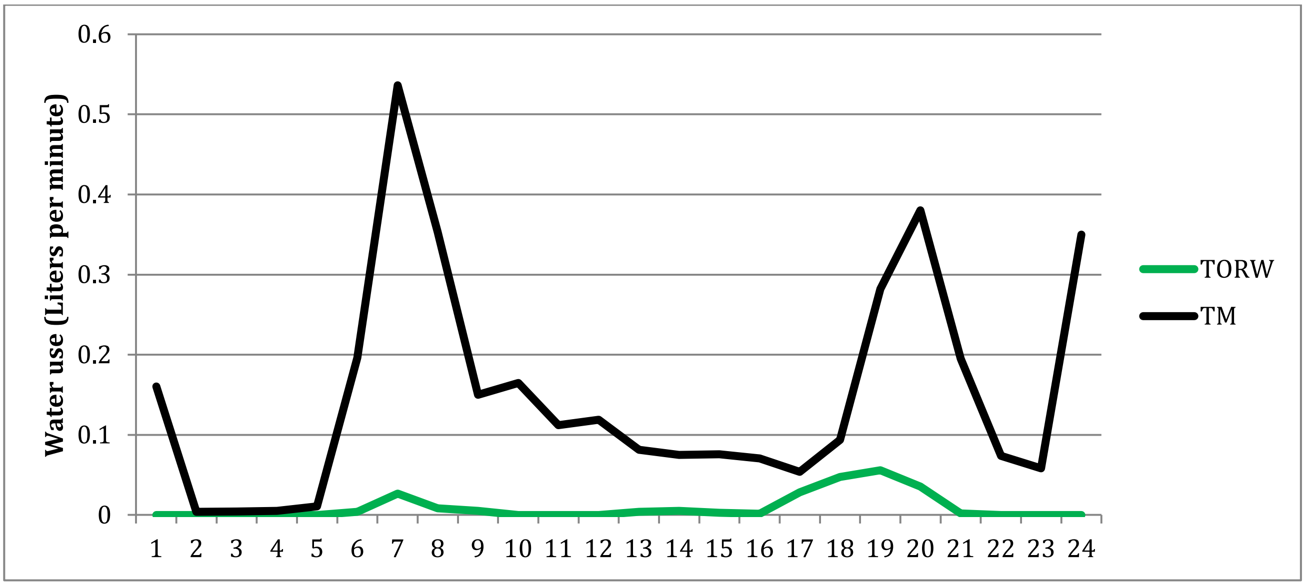



**Figure 87: Hourly profiles site 14**

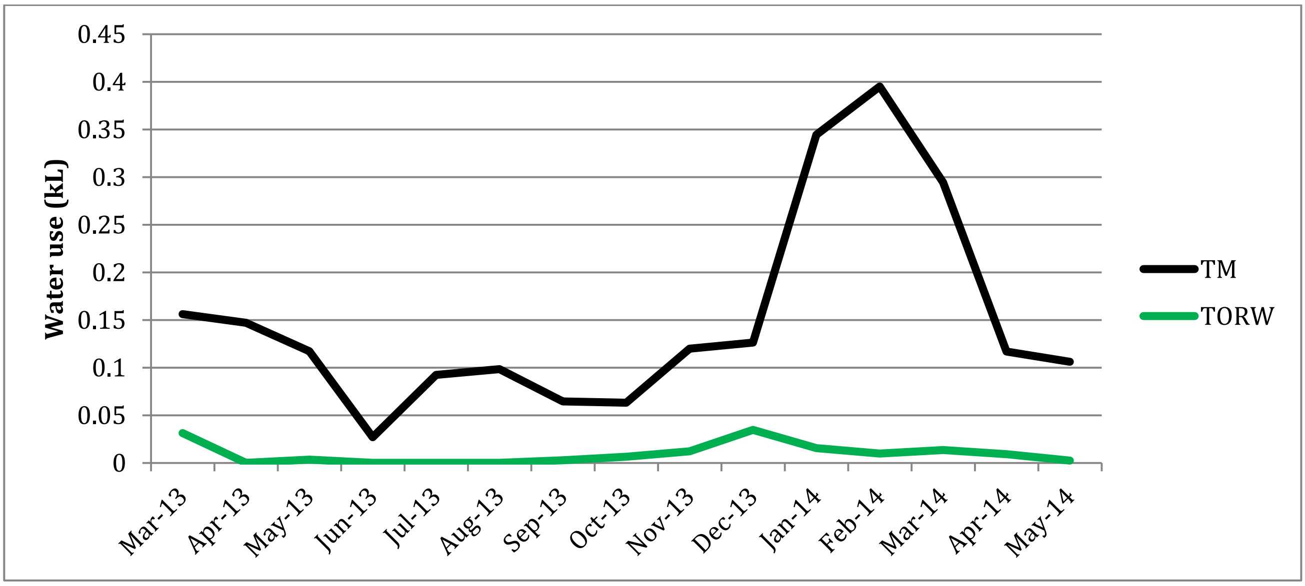



**Figure 88: Monthly use profiles site 14**

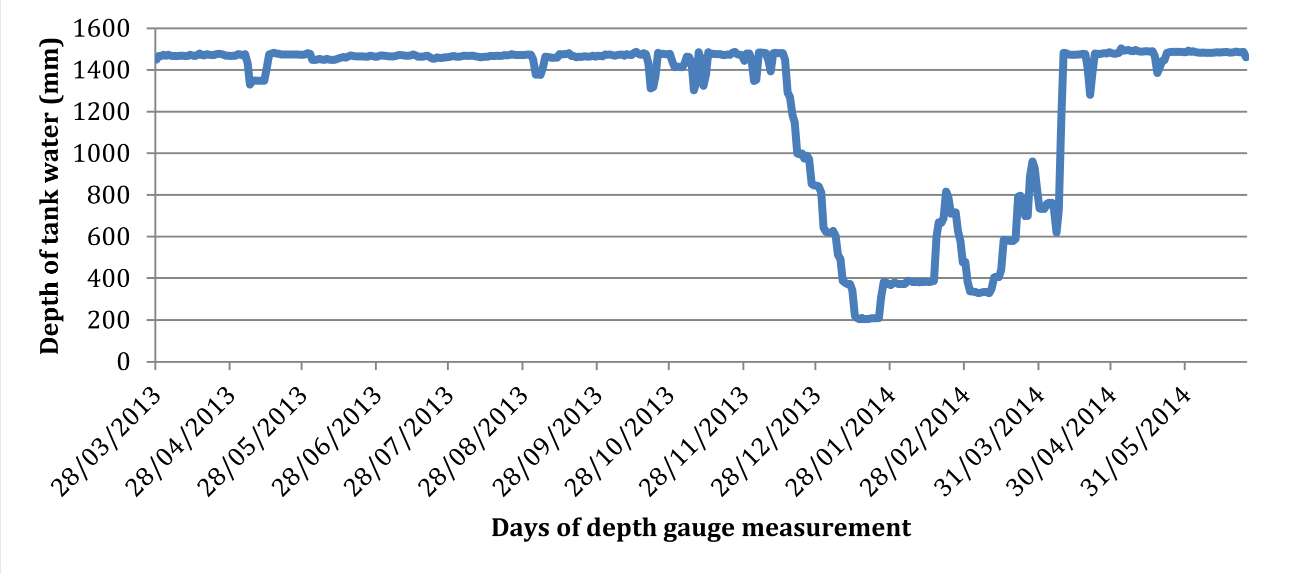



Figure 89: Depth gauge data site 14

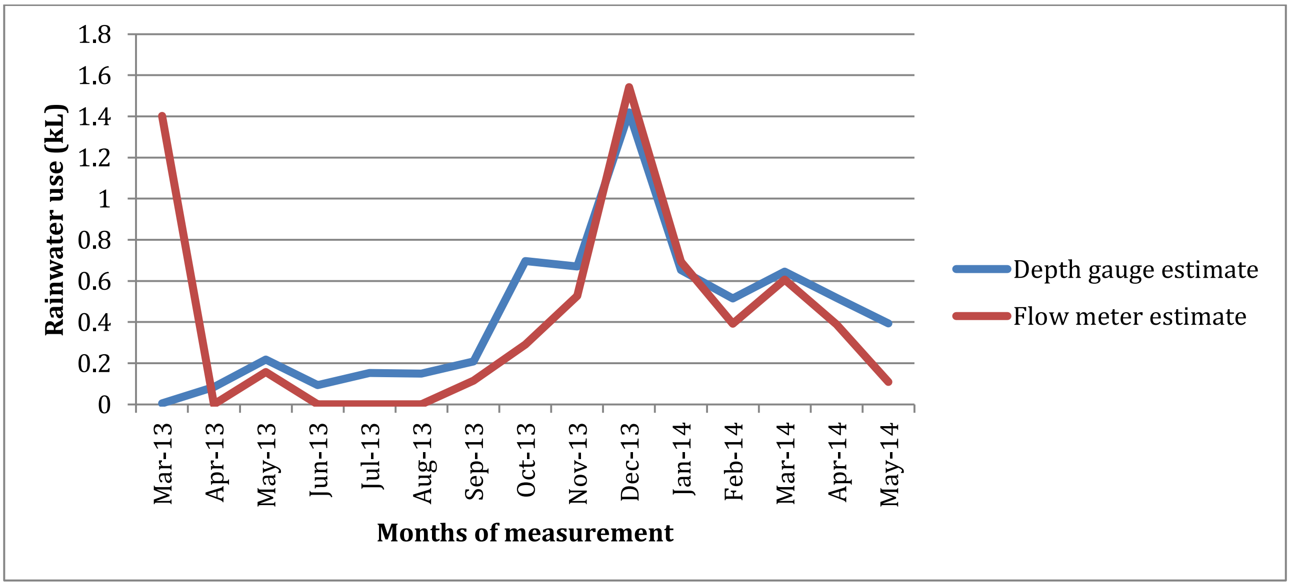



Figure 90: Estimates of rainwater use based on depth gauge data site 14

### 5.3.15. Site 15

Site 15 is in a new residential area. It has one 2kL cylindrical tank installed approximately 4 years ago. Rainwater is used for two toilets. No garden tap is connected. The pump type is Malini GP60013-1 and there is no automatic mains switch. The professionals who installed the metering equipment estimated that 13% of the roof area is connected (the owner estimated that 30% of the roof is connected). The depth gauge data shows that the tank was never empty at any stage of metering and that whilst the levels were low initially, a considerable recharge occurred in late May 2013.

Table 45: Summary variables site 15

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering* |
|---|---|---|
| Total rainwater used (TORW) | 28.0 kL | 22.5 kL |
| Energy use (EU) | 25.9 kWh | 22.6 kWh |
| Specific energy (EU/TORW) | 0.9 kWh/kL | 1.0 kWh/kL |

***Note**: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014.

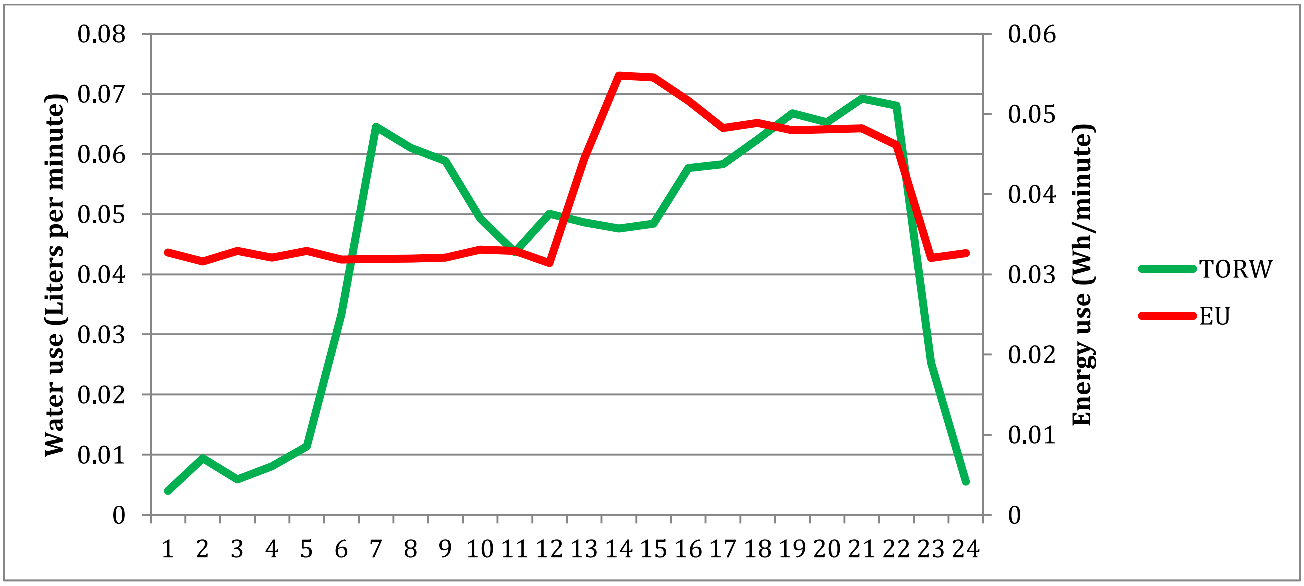



Figure 91: Hourly profiles site 15

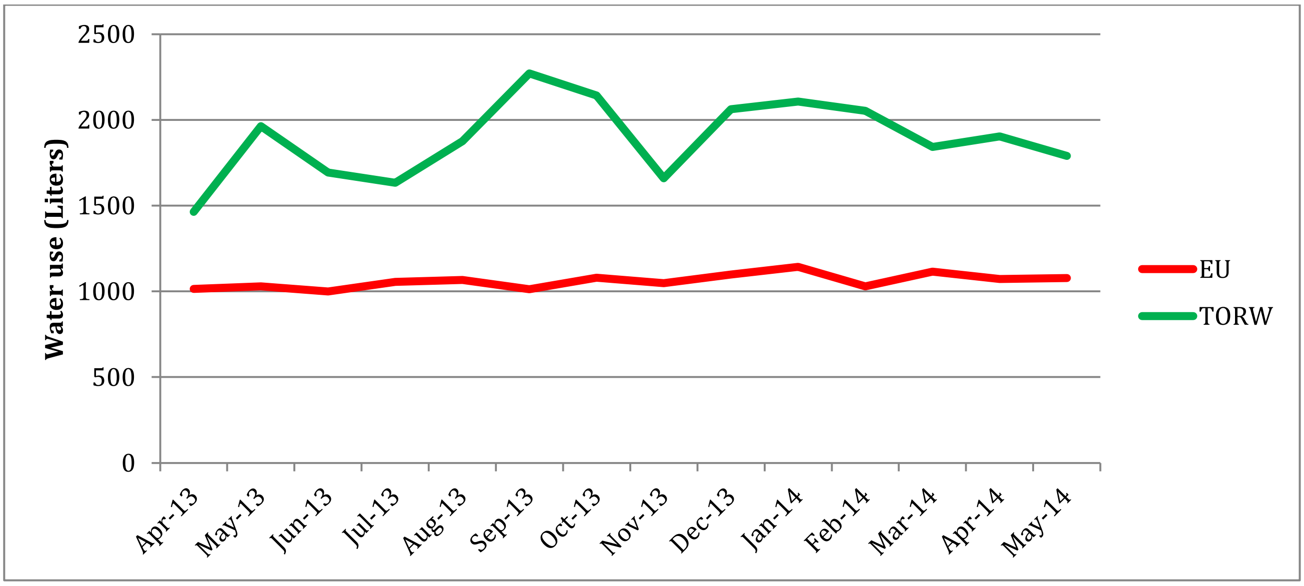



Figure 92: Monthly profiles site 15

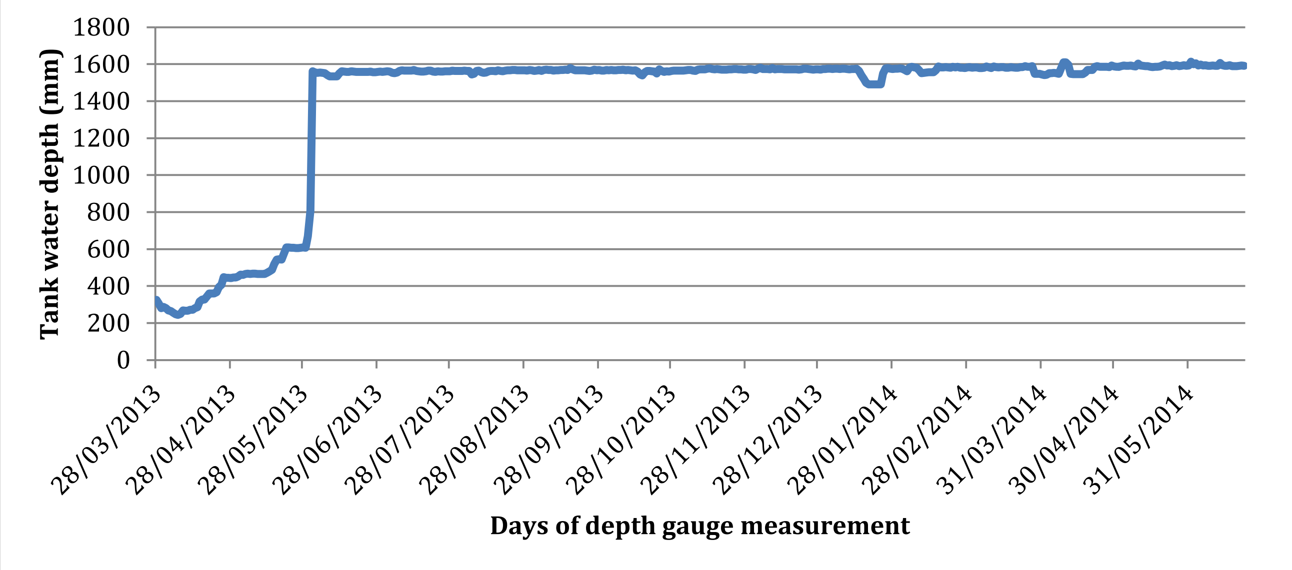



**Figure 93: Depth gauge data site 15**

### 5.3.16. Site 16

Site 16 has three bladder tanks installed; each with a volume of 6kL and all tanks inter-connected. Rainwater is used for outdoor and indoor purposes: toilets, shower, garden taps and laundry. Three garden taps are connected. The pump type is Davey HS50-06L and there is an automatic mains switch. Total mains water into the property is not being metered in this site. This is because there was already a different meter, not part of the study, on the outlet and it was not possible to add another meter for the study. The professionals who installed the metering equipment estimated that 35% of the roof area is connected. There are 8 downpipes on the house, and 6 of these are connected to the house (85%). When the plumbers visited the site to inspect the site, it was suspected that there was a leak in the bladder tank although this was not confirmed.

**Table 46: Summary variables site 16**

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering* |
|---|---|---|
| Total rainwater used indoors (TORW) | 11.6 kL | 9.9 kL |
| Total rainwater used outdoors (GT) | 16.7 kL | 14.4 kL |
| Automatic switch: mains water for meeting tank water demand (MWTU) | 36.1 kL | 30.3 kL |
| Energy use (EU) | 116.6 kWh | 98.4 kWh |
| Total rainwater use (TORW + GT) | 27.9 kL | 24.3 kL |
| Specific energy (EU/TORW + GT)** | 4.2 kWh/kL | 4.0 kWh/kL |

***Note**: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014.

****Note**: The pump is activated also whenever the mains switch operates and when this is taken into account the specific energy is a more reasonable 2.4 kWh/kL

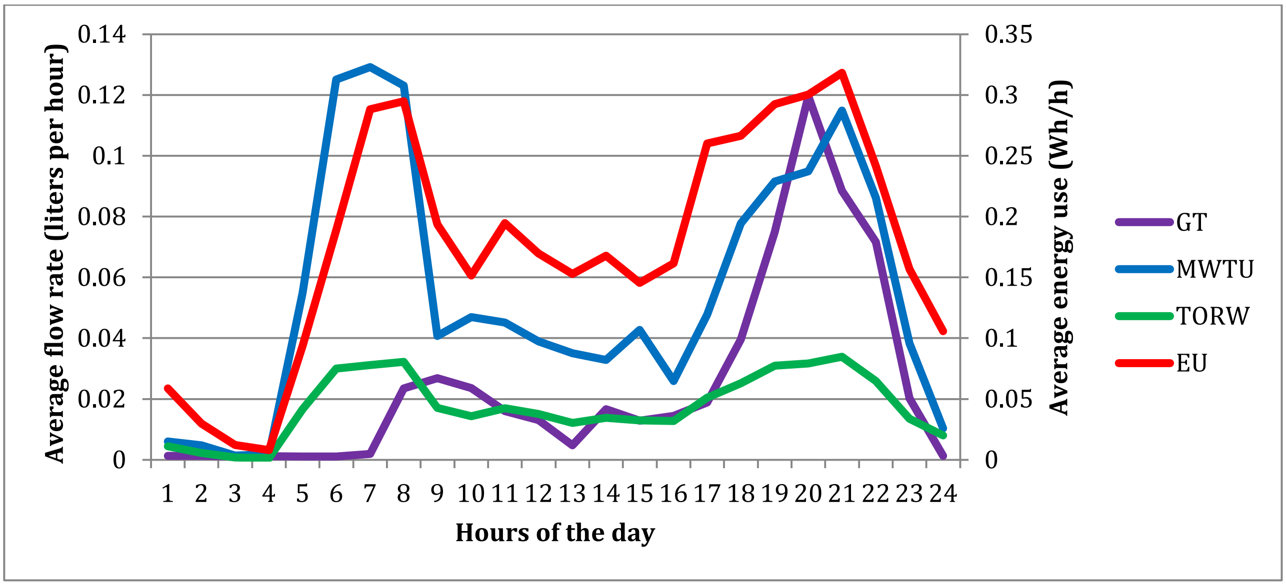



Figure 94: Hourly profile site 16

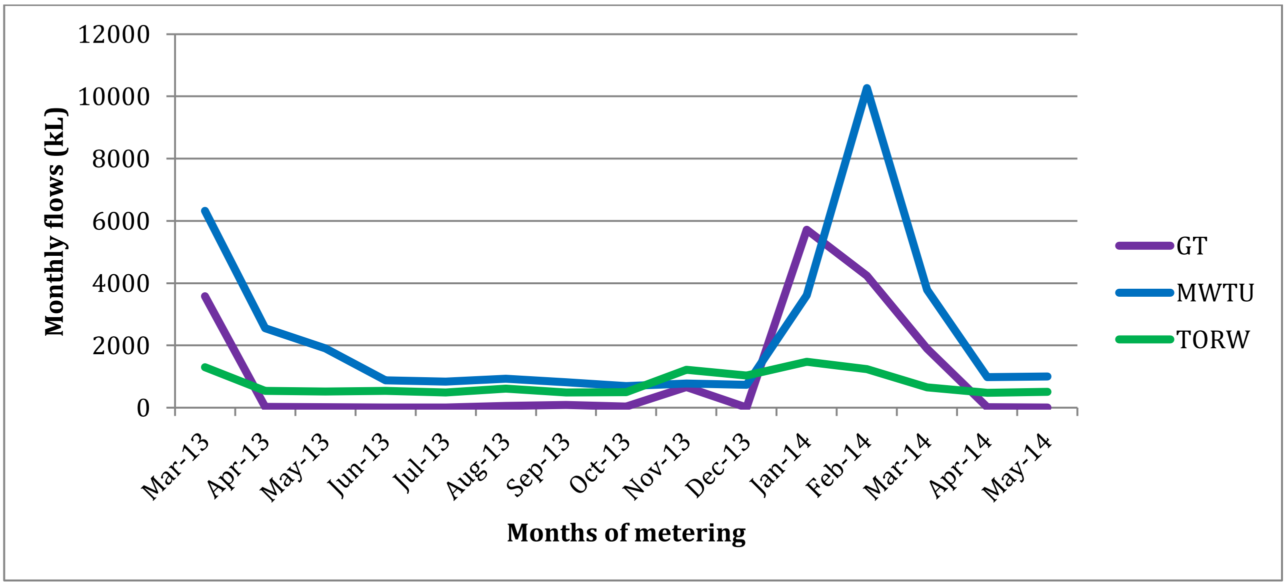



Figure 95: Monthly profiles site 16

### 5.3.17. Site 17

Site 17 has three interconnected 6 kL tanks. Rainwater is used for everything except three cold water taps; one in the kitchen, and the other two in two separate bathrooms. The pump type is Davey HP45-05 and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 20% of the roof area is connected; although that is highly questionable because the owner has reliably estimated that 100% of the roof is connected. Total mains water into the property is not being metered in this site. This site stands out considerably because of the significant amount of outdoor usage, and the significant amount of rainwater use. It is also noted that the automatic switch was activated, as it should, only when the water level in the tank was low. The total amount of tank water used in this site was 180 kL, with 147 kL being used in the first 12 months of metering. In total however only 157 kL of rainwater (i.e. not mains water through the mains switch) was used for the metering period and 128 over the first 12 months. The specific energy is the amount of pump energy per volume of rainwater being used, and this is within a normal range at 1.4-1.5 kWh/kL.

Table 47: Summary variables site 17

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering* |
|---|---|---|
| Total rainwater used (TORW) | 179.8 kL | 147.4 kL |
| Rainwater used for external purposes (GT) | 22.4 kL | 19.6 kL |
| Mains water used to meet rainwater tank demand, i.e. switch (MWTU) | 49.1 kL | 34.6 kL |
| Energy use (EU) | 218.4 kWh | 188.8 kWh |
| Specific energy (EU/TORW-GT) | 1.2 kWh/kL | 1.3 kWh/kL |

***Note**: The full metering period was March 2013-May 2014. The first 12 months were March 2013 – February 2014.

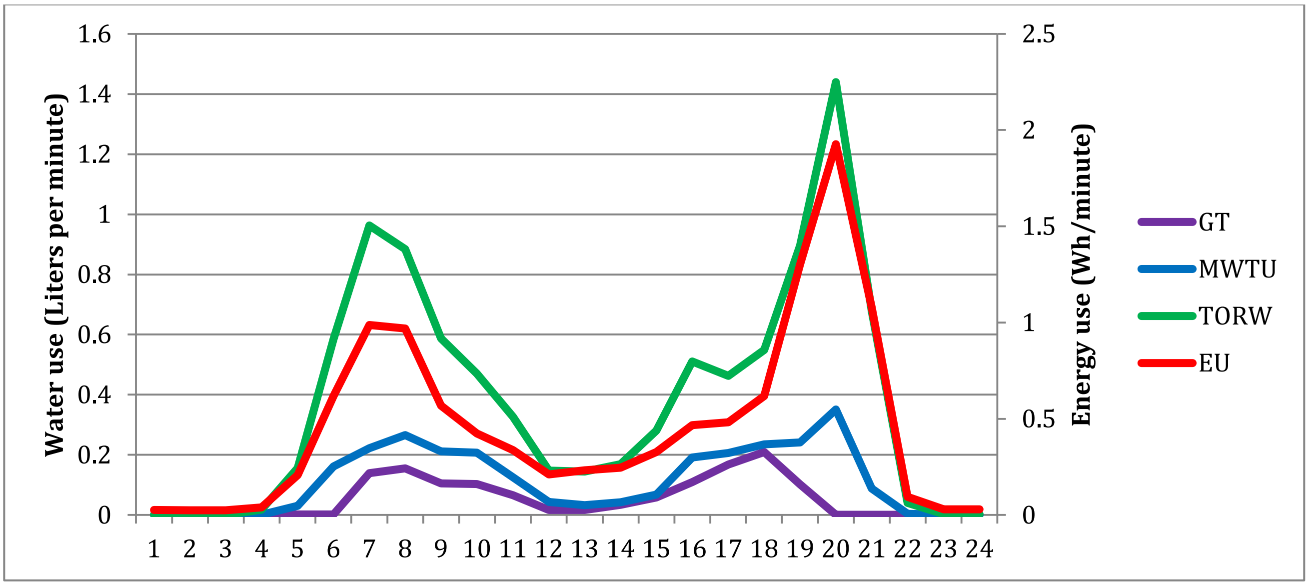



Figure 96: Hourly profiles site 17

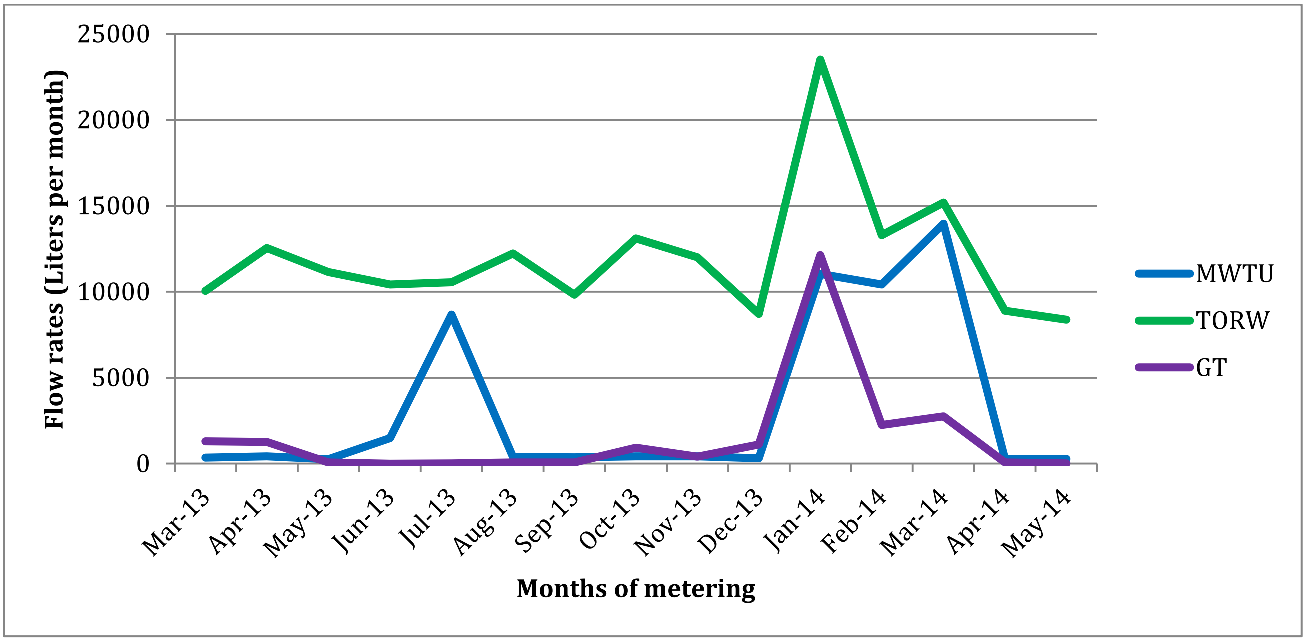



**Figure 97: Monthly profiles site 17**

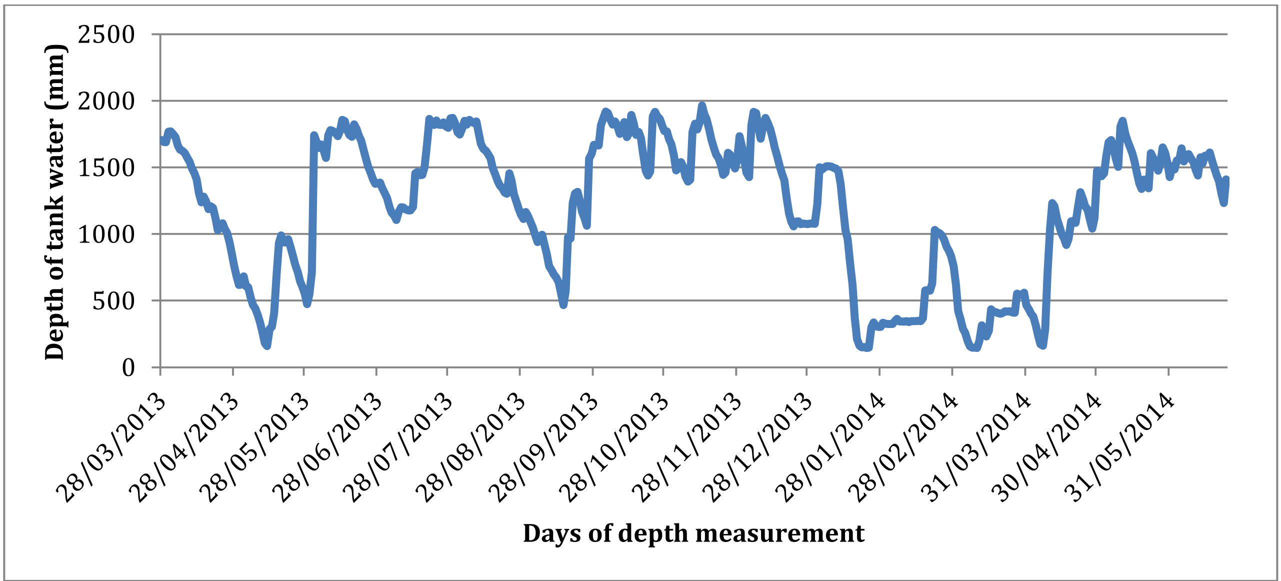



**Figure 98: Depth gauge data site 17**

### 5.3.18. Site 18

Site 18 has one rectangular 3 kL tank. Rainwater is used for three toilets and one garden tap. There are two residents in the house. The pump type is Power XKJ-804SE and there is an automatic mains switch. The professionals who installed the metering equipment estimated that 50% of the roof area is connected. There are 6 downpipes on the house of which 2 are connected to the tank. Total mains water into the property is not being metered in this site. Depth gauge data indicates regular use and it is noted that the tank was never empty during the depth gauge monitoring, and that the mains switch was only activated in February 2014 (outside the depth gauge metering period), towards the end of the hot and dry summer. This indicates that the mains switch is operational as it should. External water use in this site is extremely low (40 liters over the metering period) and there is only a small amount of times that the automatic switch was activated, supplying a total of 126 liters over the metering period.

The specific energy for the pump in this site is relatively high. It is noted that 42% of the energy used by the pump was single pulses with no water use, i.e. with the pump in standby mode. When this standby energy is excluded, the specific energy is at the lower end of the normal range (1 kWh/kL). As can be seen per Figure 101 this tank shows regular use and has been within 50 mm of being full (i.e. depth of tank water >= 1056 mm) for only 7% of the time. The time when the tank was nearly empty in February 2014 also coincides with the incident according to flow meters when the automatic switch was activated. This indicates that the automatic switch is indeed fully functional.

**Table 48: Summary variables site 18**

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering* |
|---|---|---|
| Total rainwater used indoor (TORW) | 13.4 kL | 10.4 kL |
| Garden tap (GT) | 0.04 kL | 0.04 kL |
| Automatic switch (MWTU) | 0.1 kL | 0.1 kL |
| Energy use (EU) | 31.0 kWh | 24.3 kWh |
| Energy use in standby** | 13.0 kWh | 13.9 kWh |
| Total  rainwater use (TORW + GT) | 13.4 kL | 10.3 kL |
| Specific energy (EU/TORW+GT) | 2.3 kWh/kL | 2.3 kWh/kL |
| Specific energy excl. standby mode | 1 kWh/kL | 1 kWh/kL |

***Note**: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014.

****Note**: The energy expended by the pump in standby mode is calculated because of the relatively high energy use, to show the main cause for this high usage. Standby energy is when the pump uses energy (i.e. 1Wh pulses) at times when no water is being used.

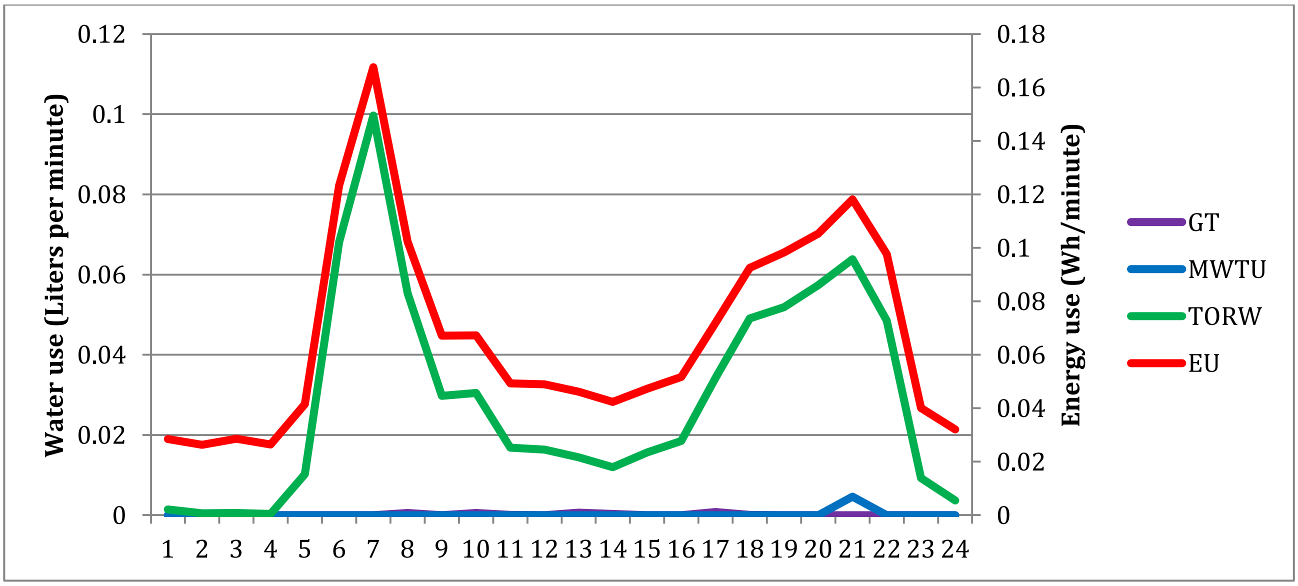



**Figure 99: Hourly profiles site 18**

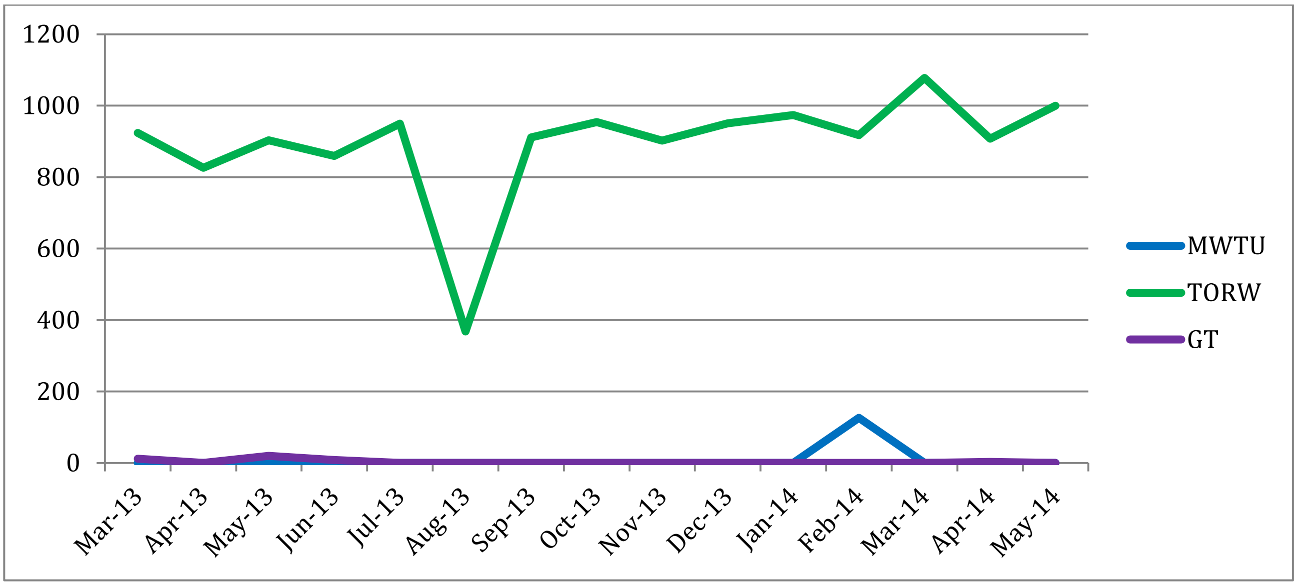



**Figure 100: Monthly profiles site 18**

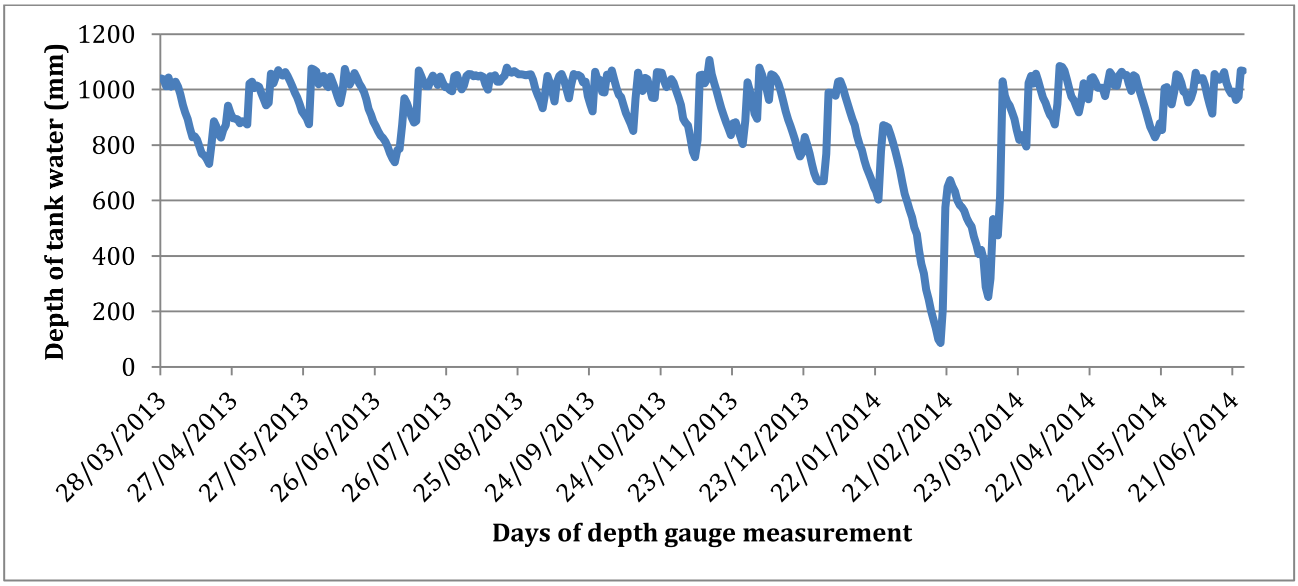



**Figure 101: Depth of tank water site 18**

### 5.3.19. Site 19

Site 19 has two 1.9 kL slimline tanks. Rainwater is used for toilets and one garden tap; although after the metering concluded the householder has noted that no rainwater was used for outdoor purposes during the metering period. There are two residents in the house. The pump type is Hyjet DHJ800 and there is a trickle top up system (when the water level falls below a threshold, the tank is filled up with mains water through a trickle system). There are 6 downpipes on the house of which only one is connected to the tank. Total mains water into the property is not being metered in this site. There should be depth gauge data available in this site but this data has still not been provided.

No external water use has picked up by the flow meters in this site and there is only a small amount of times when the trickle top up system was activated, supplying a mere total of 1 kL liters over the metering period. The specific energy for the pump in this site is relatively high at 3.2 kWh/kL. It is noted that 35% of the energy used by the pump was single pulses with no water use, i.e. with the pump in standby mode. When this standby energy is excluded, the specific energy is within the normal range (1.8 kWh/kL). It is also noted that this property had a two-storey building which could have impacted on pump energies. The annual total rainwater used in this site was 7.2 kL which is relatively low. The likely reason for the low rainwater use is the relatively low demand.

There are depth gauge measurements for this site from November 2013 onwards, as per Figure 104 which shows the daily water levels throughout the measurement period. It is notable that the tank has not run dry and that there are regular withdrawals of water from the tank. Only about 16% of the time has the tank been within 50 mm of being full. The depth gauge data can again be used to estimate rainwater use from the tank (using an error margin of 5 mm and an estimated base area of 0.51 $m^2$) and again we find a slight discrepancy between that which is being measured with flow meters and that which is being measured with depth gauges, as per Figure 105.

**Table 49: Summary variables site 19**

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering* |
|---|---|---|
| Total rainwater used indoor (TORW) | 13.7 kL | 8.0 kL |
| Garden tap (GT) | 0 kL | 0 kL |
| Trickle top-up system (MWTU) | 1.4 kL | 0.8 kL |
| Energy use (EU) | 39.0 kWh | 22.5 kWh |
| Total rainwater use (TORW +GT – MWTU) | 12.3 kL | 7.2 kL |
| Specific energy (EU/TORW+GT-MWTU) | 3.2 kWh/kL | 3.1 kWh/kL |
| Specific energy when excl. standby mode** | 1.8 kWh/kL | 1.8 kWh/kL |

*__Note__: Metering period: March 2013-May 2014. First 12 months: March 2013-February 2014.

**__Note__: The energy expended by the pump in standby mode is calculated because of the relatively high energy use, to show the main cause for this high usage. Standby energy is when the pump uses energy (i.e. 1Wh pulses) at times when no water is being used.

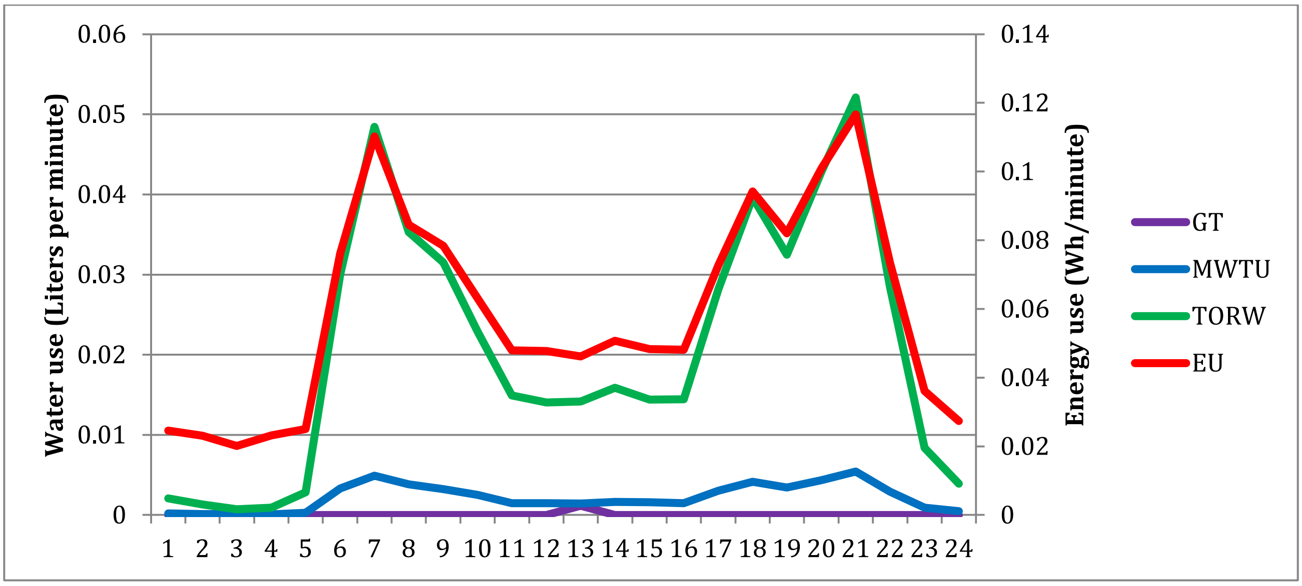



**Figure 102: Hourly profiles site 19**

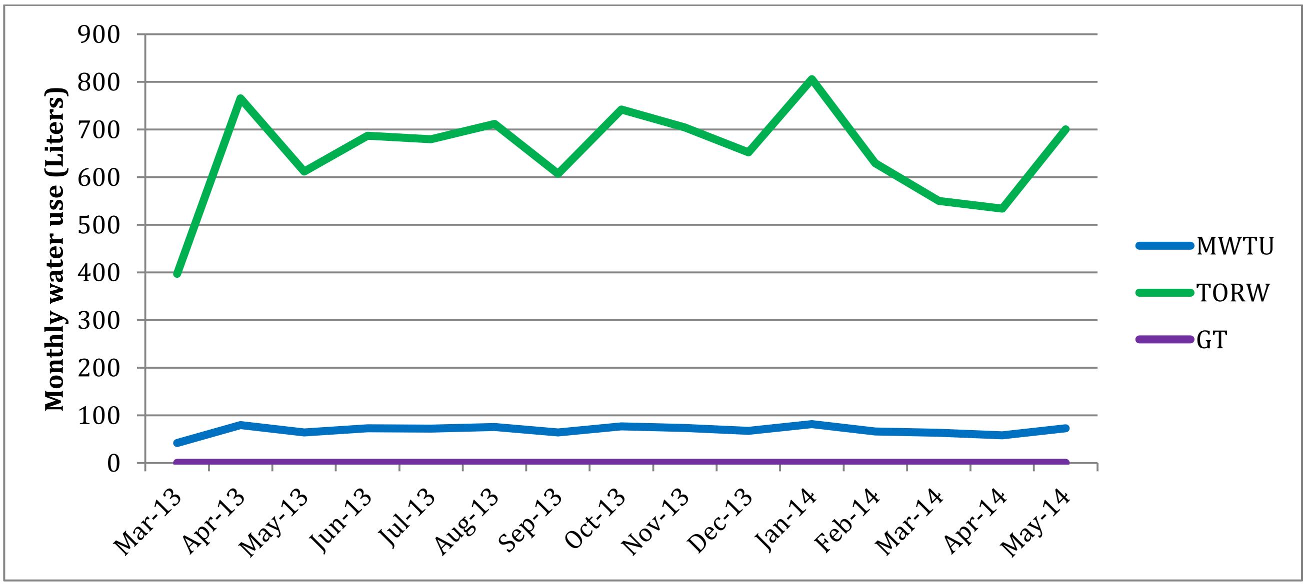



**Figure 103: Monthly profiles site 19**

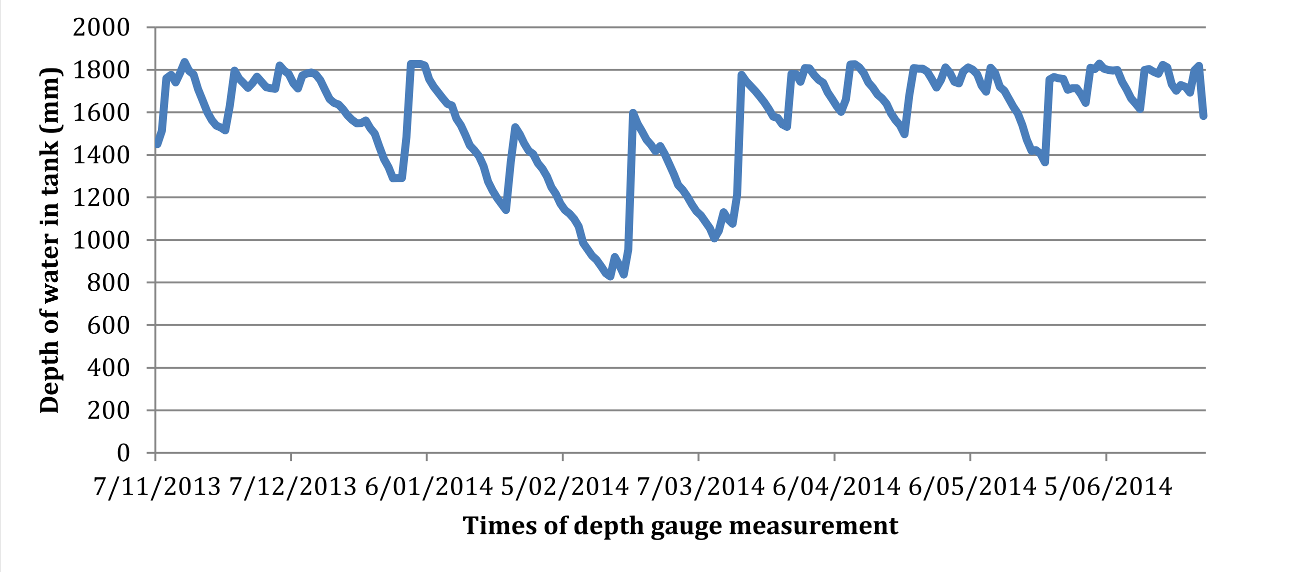



**Figure 104: Depth gauge measurements site 19**

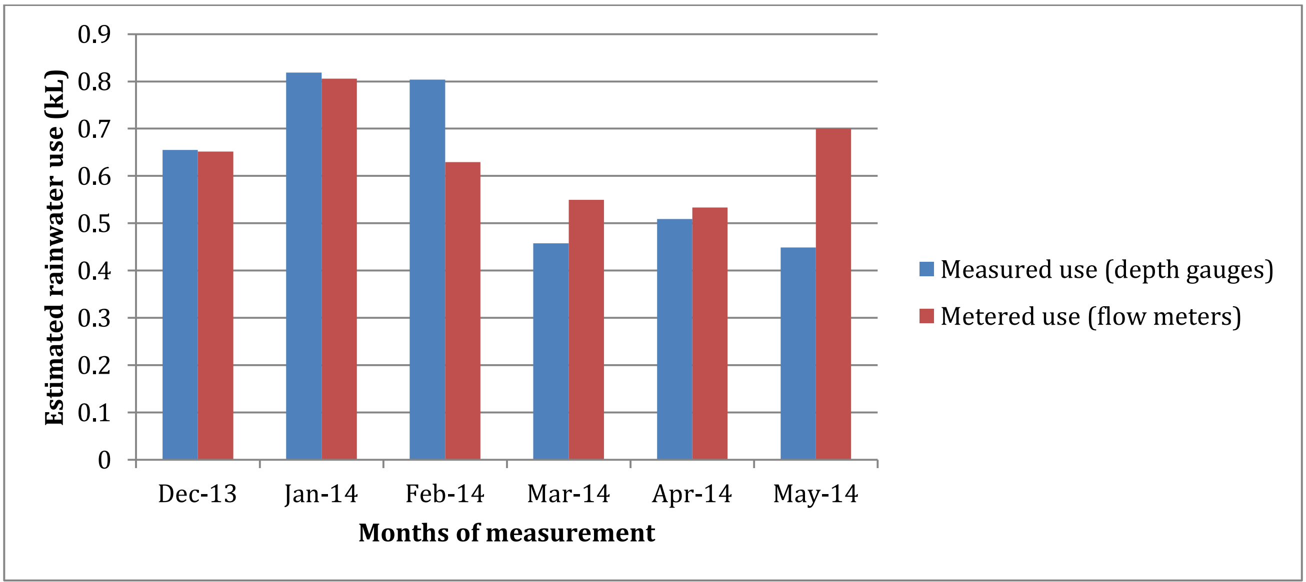



**Figure 105: Rainwater use estimate comparison site 19**

### 5.3.20. Site 20

Site 20 has an 8 kL tank installed about 3 years ago. Rainwater is used for outdoor purposes only: garden, car, outside cleaning. There are two residents in the house. The pump type is Superior SP70 and there is no automatic switch or trickle top-up system. There are 3 downpipes on the house of which only one is connected to the tank. Professionals estimated that approximately 33% of the roof is connected to the tank. Total mains water into the property is not being metered in this site. There should be depth gauge data available in this site but this data has still not been provided. The specific energy for the pump in this site is relatively high: 2.1kWh/kL. It is noted that virtually none of the energy used by the pump was in standby mode. One may infer that the pump is only turned on when water is about to be used. The annual total rainwater used in this site was 5 kL which is relatively low and most of this occurred during the hot and dry summer months. The likely reason for the low rainwater use is the relatively low demand; i.e. only external use.

Table 50: Summary variables site 20

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering** |
|---|---|---|
| Total rainwater used (TORW) | 8.5 kL | 5 kL |
| Energy use (EU) | 17.1 kWh | 10.5 kWh |
| Specific energy (EU/TORW) | 2.0 kWh/kL | 2.1 kWh/kL |
| Specific energy when excl. standby mode*** | 2.0 kWh/kL | 2.1 kWh/kL |

***Note**: The full metering period is 1/3/2013 – 31/5/2014.

****Note**: This refers to March 2013 – February 2014.

*****Note**: The energy expended by the pump in standby mode is calculated because of the relatively high energy use, to show the main cause for this high usage. Standby energy is when the pump uses energy (i.e. 1Wh pulses) at times when no water is being used.

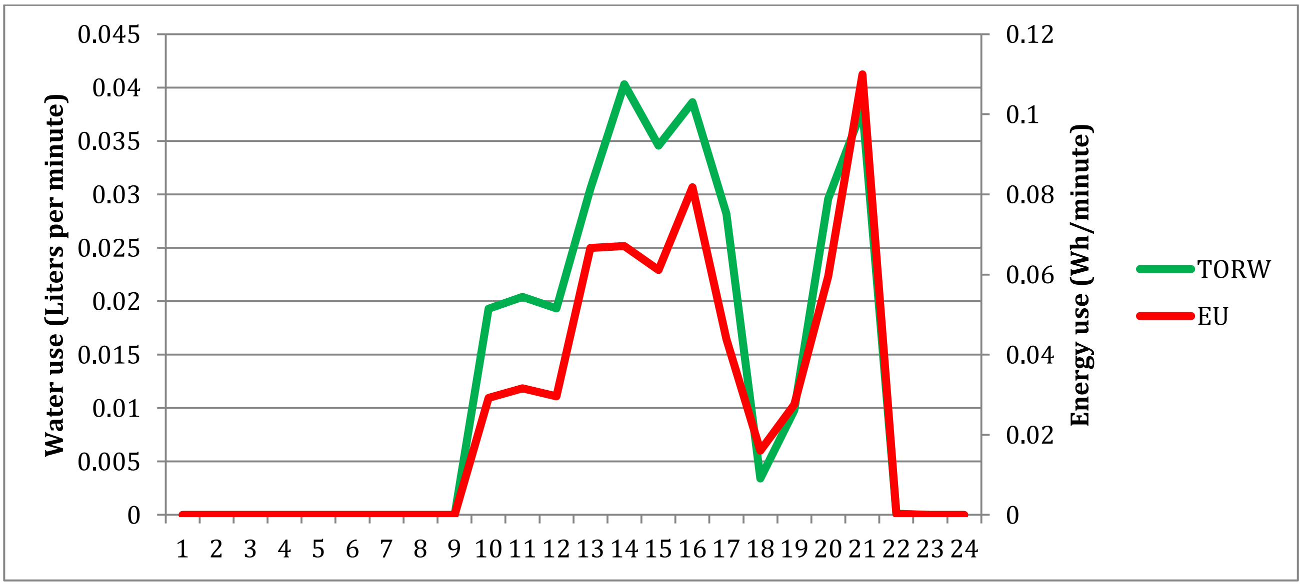



Figure 106: Hourly profiles site 20

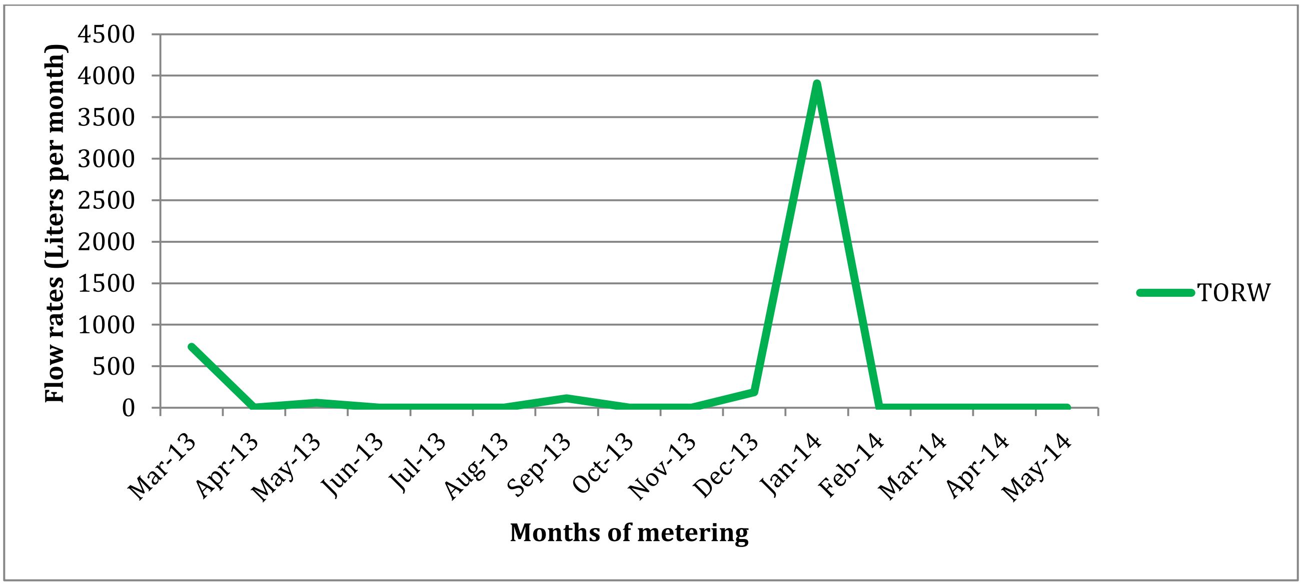



**Figure 107: Monthly profiles site 20**

### 5.3.21. Site 21

Site 21 has a 5 kL tank installed. Rainwater is used for outdoor purposes only: garden irrigation and car wash. There are four residents in the house. The pump type could not be determined and there is no automatic switch or trickle top-up system. There are seven downpipes on the house of which only two are connected to the tank. Professionals estimated that approximately 25% of the roof is connected to the tank. The site also involves some considerable height differences in the property which means that pump energy is likely to be relatively higher than what may otherwise be expected. Total mains water into the property is not being metered in this site. The specific energy for the pump in this site is relatively high: 3.2kWh/kL. It is noted that virtually none of the energy was used by the pump in standby mode. It is likely that the pump is only turned on when water is to be used. The high specific energy could possibly be explained by a considerable height difference at this site. The annual total rainwater used in this site was 2.9 kL which is relatively low. The likely reason for the low rainwater use is the relatively low demand; i.e. only external use.

**Table 51: Summary variables site 21**

| Summary variable | Total over the full metering period* | Total for the 12 months from start of metering** |
|---|---|---|
| Total rainwater used (TORW) | 8.2 kL | 2.9 kL |
| Energy use (EU) | 23.5 kWh | 9.7 kWh |
| Specific energy (EU/TORW) | 2.9 kWh/kL | 3.3 kWh/kL |

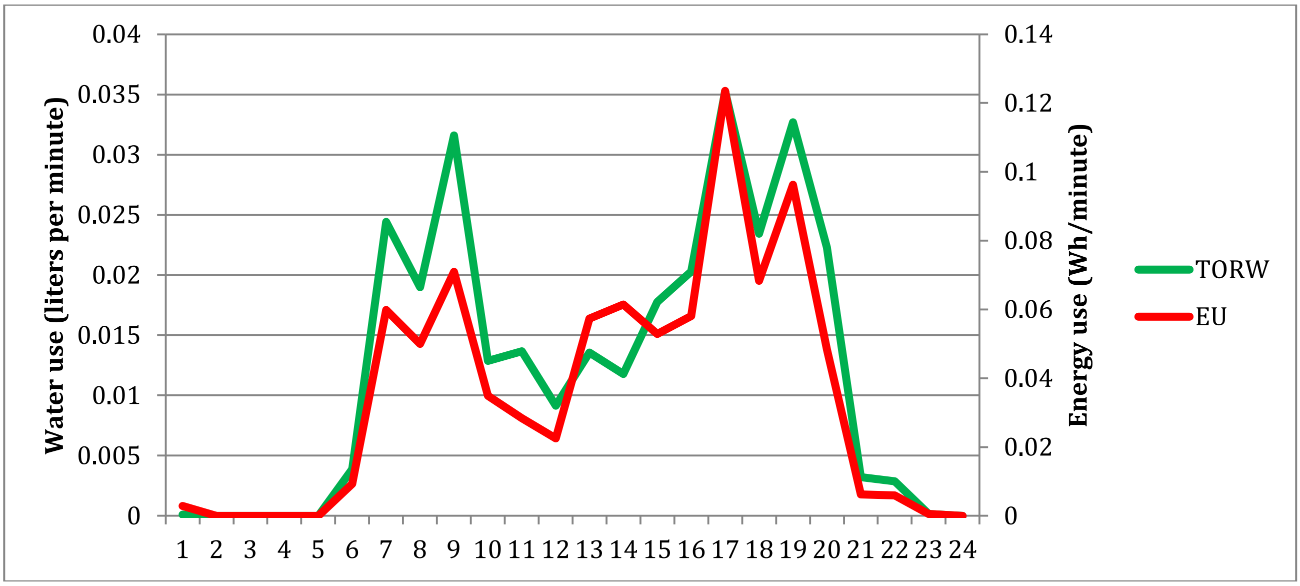



Figure 108: Hourly profiles site 21

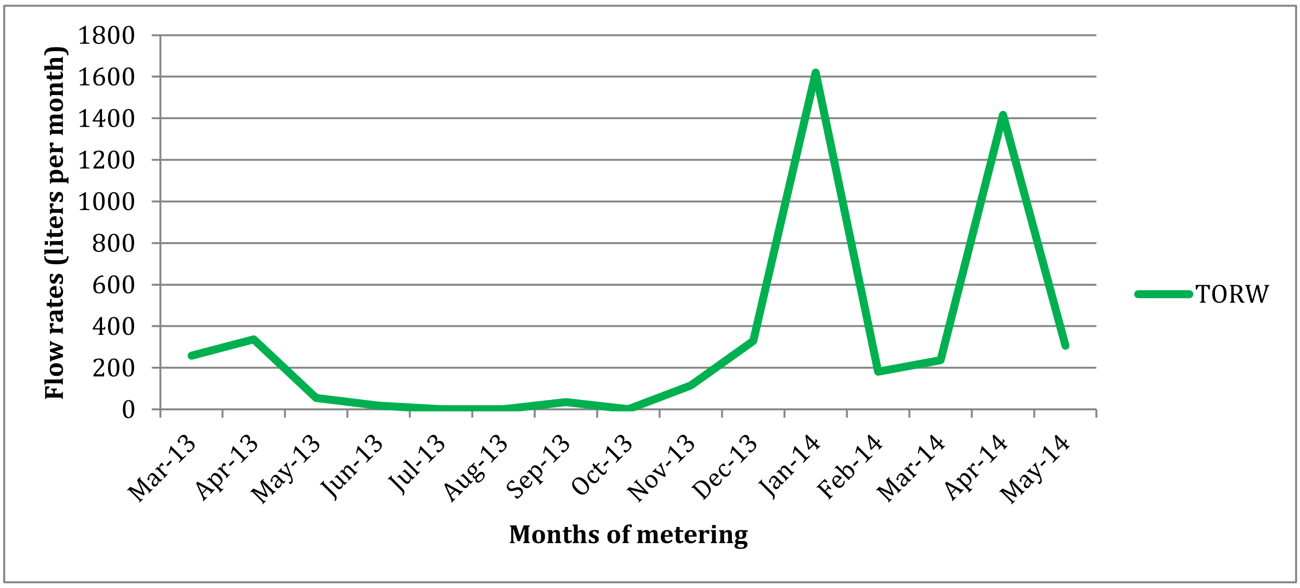



Figure 109: Monthly profiles site 21

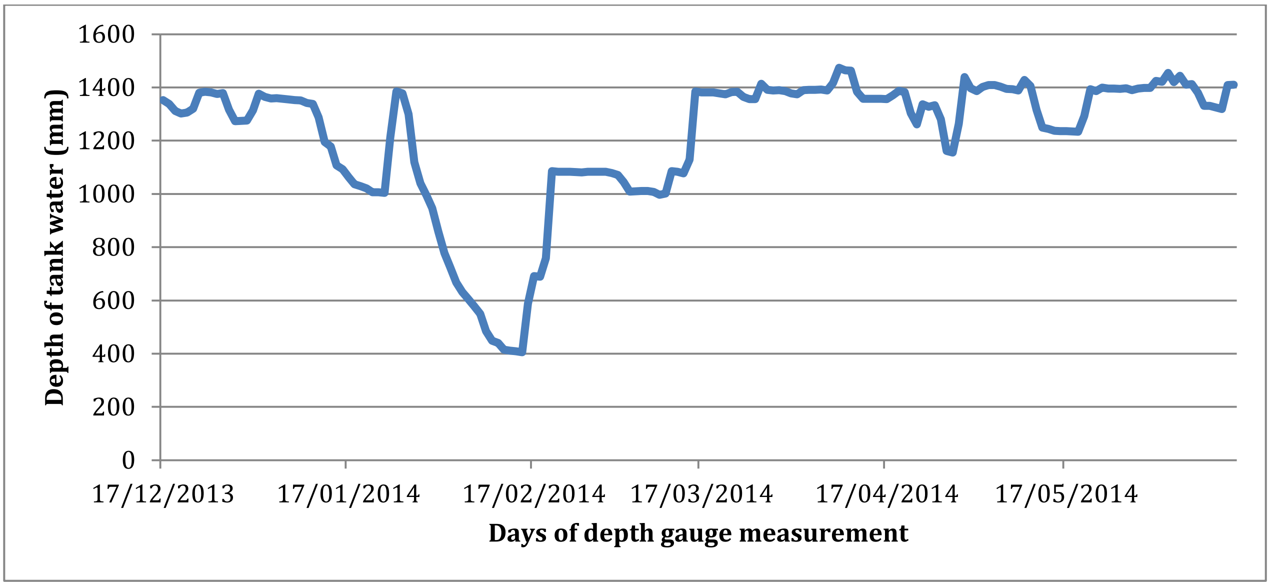



Figure 110: Depth gauge measurements site 21

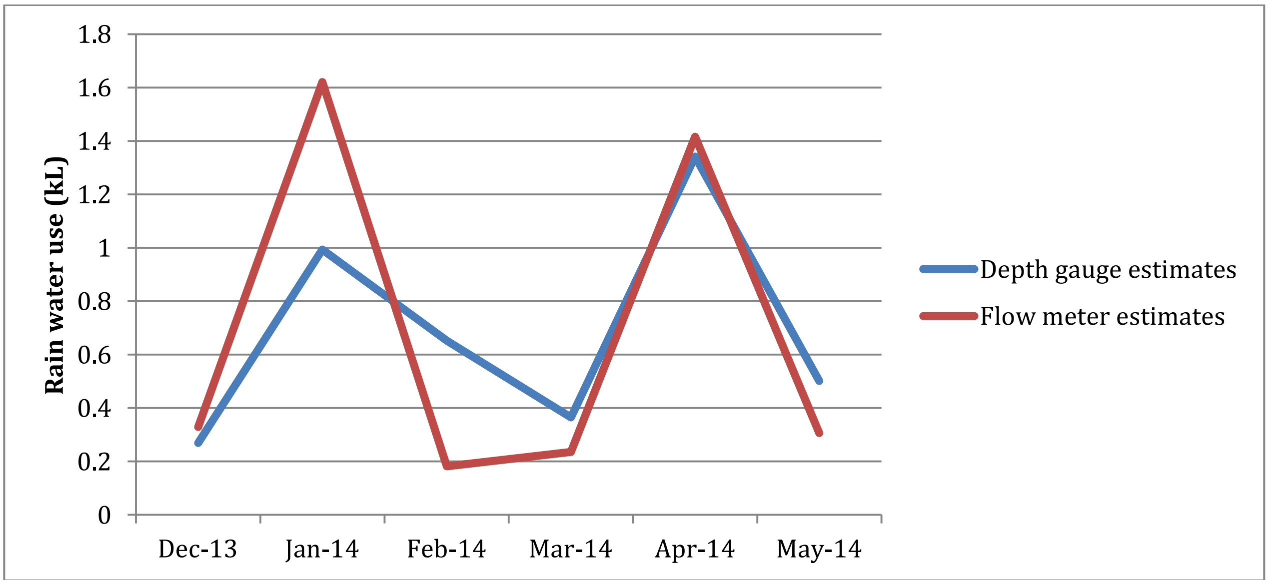



Figure 111: Depth gauge and flow meter estimates of rainwater use site 21*

*Note: So far only the depth gauge data from December 2013-May 2014 has been supplied.

## 5.4. Aggregate metering results

The results from the metering study are shown in Table 53 and Table 54. Table 53 shows the results from the various site meters over the entire metering period and Table 54 shows the results over 12 months (or the extrapolation to 12 months in the case of 2 sites). For mapping of metering sites against inspection data, see Appendix G. Because many of the sites are relatively different, this data however needs to be synthesized before it is possible to make much sense of it. This has been done in Table 55. Table 52 has information about average rainwater use. It is also noted that the rainwater use varies considerably between sites with some sites having rainwater use significantly higher than the average. Specifically, site 17 has an extremely high rainwater use at 147 kL, and this is an outlier that shows the very significant water saving potential of rainwater tanks if they have a combination of a good setup, large collection area, and high demand for tank water. One of the outdoor only sites, number 4, has a very high outdoor demand. It is noted that this is a rural property and that this would explain the high demand for outdoor water. It is also noted that a relatively high percentage of sites has quite a low indoor tank water demand. There should be potential to increase this by connecting the rainwater to additional toilets, laundry or other.

**Table 52: Average results in metering sites**

| Set up | Average rainwater use - potential* | Average rainwater use - actual | Average rainwater use indoors | Average rainwater use outdoors | Average specific energy |
|---|---|---|---|---|---|
| **External only** | 11.6 | 11.6 | - | 11.1 | 1.36 |
| **Indoor and outdoor** | 42.6 | 33.0 | 36.9 | 5.6 | 1.96 |
| **Indoor only** | 31.9 | 27 | 31.9 | - | 1.90 |

*__Note__: This refers to the potential and not the metered use.

**Table 53: Metering summary per meter for the full time of metering**

| Site ID | TM | TORW | MWTU | GT | EU |
|---|---|---|---|---|---|
| 1 | | 34.0 | 0.1 | | 36.5 |
| 2 | | 64.2 | | | 217.5 |
| 3 | | | | 2.4 | 2.0 |
| 4 | 598.0 | 60* | | | 0.0 |
| 5 | | 48.0 | 6.0 | 1.2 | 46.4 |
| 6 | 84.5 | 38.6 | 19.5 | 6.0 | 38.7 |
| 7 | 144.6 | | | 6.6 | 5.1 |
| 8 | 48.2 | 15.2 | 14.2 | | 16.7 |
| 9 | 169.8 | 39.9 | 36.8 | 7.1 | 10.4 |
| 10 | 166.6 | 30.9 | 28.6 | 11.5 | 26.9 |
| 11 | 8.8 | 69.7 | 58.3 | 2.5 | 38.4 |
| 12 | 167.9 | 14.4 | | 0.0 | 11.5 |
| 13 | 86.9 | 54.4 | | 1.2 | 98.7 |
| 14 | 67.6 | 6.2 | | 0.0 | |
| 15 | | 28.0 | | | 25.9 |
| 16 | | 11.6 | 36.1 | 16.7 | 116.6 |
| 17 | | *179.8*** | 49.1 | 22.4 | 218.4 |
| 18 | | 13.4 | 0.1 | 0.0 | 31.0 |
| 19 | | 13.7 | 1.4 | 0.0 | 39.0 |
| 20 | | 8.5 | | | 17.1 |
| 21 | | 8.2 | | | 23.5 |
| *Average* | *154* | *39* | *23* | *5.5* | *51* |
| *Median* | *116* | *31* | *20* | *2.5* | *29* |

*__Note__: Estimated based on depth gauge data.
****Note:** Outliers noted.

**Table 54: Metering summary per site and per meter for 12 months**

| Site ID | TM | TORW | MWTU | GT | EU |
|---|---|---|---|---|---|
| 1 | | 25.9 | 0.0 | | 27.7 |
| 2 | | 58.7 | | | 194.1 |
| 3 | | | | 2.4 | 2.0 |
| 4 | 318.0 | 48.0 | | | 0.0 |
| 5 | | 38.7 | 5.4 | 0.9 | 29.8 |
| 6 | 84.5 | 38.6 | 19.5 | 6.0 | 38.7 |
| 7 | 108.2 | | | 6.5 | 4.9 |
| 8 | 105.7** | 20.2** | 18.9** | | 24.0** |
| 9 | 144.6 | 33.6 | 33.4 | 7.1 | 5.3 |
| 10 | 133.2 | 25.6 | 23.2 | 10.0 | 26.5 |
| 11 | 7.4 | 61.2 | 49.7 | 2.5 | 38.4 |
| 12 | 214.3** | 14.6** | | 0.0** | 11.6** |
| 13 | 64.8 | 46.7 | | 1.1 | 77.1 |
| 14 | 52.9 | 4.9 | | 0.0 | |
| 15 | | 22.5 | | | 22.6 |
| 16 | | 9.9 | 30.3 | 14.4 | 98.4 |
| 17 | | 147.4 | 34.6 | 19.6 | 188.8 |
| 18 | | 10.4 | 0.1 | 0.0 | 24.3 |
| 19 | | 8.0 | 0.8 | 0.0 | 22.5 |
| 20 | | 5.0 | | | 10.5 |
| 21 | | 2.9 | | | 9.7 |
| *Average* | *124* | *33* | *20* | *5* | *43* |
| *Median* | *107* | *26* | *20* | *2.5* | *24* |

****Note**: This estimate is based on data of a partial year which has been extrapolated to a full year.

The link between rainfall and rainwater use potential is explored in Table 56. Contrary to what could be expected if the rainwater use was demand driven (less rainfall means more demand for gardening), as can be seen in Figure 114, there is a weak relationship between rainfall and outdoor rainwater use. This trends towards rainwater use being supply driven could be explained by the observation that for most tanks, the only times that tanks have run dry has been in the dry summer months when outdoor watering activities are most prevalent. This is also consistent with the observation that the relationship between rainfall and indoor water use is virtually non-existent, as per Figure 115. This again reinforces the notion that tanks will primarily only become empty during the hot dry summer months; often in response to high levels of outdoor water usage.

Table 55: Summary information

| Site ID | Category | Rainwater use total (kL) | Rainwater use indoor (kL)** | Rainwater use outdoor (kL)** | Specific energy (kWh/kL) |
|---|---|---|---|---|---|
| 1 | Indoor only | 26.0 | 26.0 | - | 1.1 |
| 2 | Indoor only | 59.0 | 59.0 | - | 3.4 |
| 3 | External only | 2.4 | - | 2.4 | 0.8 |
| 4 | External only | 48.0 | - | 48.0 | 0.0 |
| 5 | Indoor and outdoor | 39.0 | 37.9 | 1.1 | 1.5 |
| 6 | Indoor and outdoor | 38.6 | 32.6 | 6.0 | 1.0 |
| 7 | External only | 6.5 | - | 3.2 | 0.8 |
| 8 | Indoor only | 1.3 (20.2) | 20.2 | - | 1.2 |
| 9 | Indoor and outdoor | 7.3 (40.7) | 33.6 | 7.1 | 1.0 |
| 10 | Indoor and outdoor | 12.3 (35.6) | 25.6 | 10.0 | 1.9 |
| 11 | Indoor and outdoor | 14.0 (63.6) | 61.1 | 2.5 | 2.7 |
| 12 | Indoor and outdoor | 14.6 | 14.6 | 0.0 | 0.8 |
| 13 | Indoor and outdoor | 46.7 | 45.6 | 1.1 | 1.8 |
| 14 | External only | 4.9 | - | 4.9 | Unknown |
| 15 | Indoor only | 22.5 | 22.5 | - | 1.0 |
| 16 | Indoor and outdoor | 24.3 | 9.9 | 14.4 | 4.2 |
| 17 | Indoor and outdoor | 147.4 | 127.8 | 19.6 | 1.2 |
| 18 | Indoor and outdoor | 10.3 | 10.3 | 0.0 | 2.3 |
| 19 | Indoor and outdoor | 8.0 | 7.2 | 0.0 | 3.2 |
| 20 | External only | 5.0 | - | 5.0 | 2.1 |
| 21 | External only | 2.9 | - | 2.9 | 3.3 |
| **Average** | **All** | **25.7 (31.7)** | **36.0** | **7.5-9.2*** ** | **1.8** |

*__Note__: This column provides an estimate of potential rainwater use in sites where the automatic switch was turned off or broken.
**__Note__: Here we are using the numbers as if the automatic mains switches were functional and tank water demand was met with rainwater rather than mains water.
***__Note__: The lower average value, 7.5kL, refers to those sites where external water use has been registered, whilst the higher average value, 9.2kL, refers to a set of sites which excludes those three sites where external use has been metered but no usage has been registered.

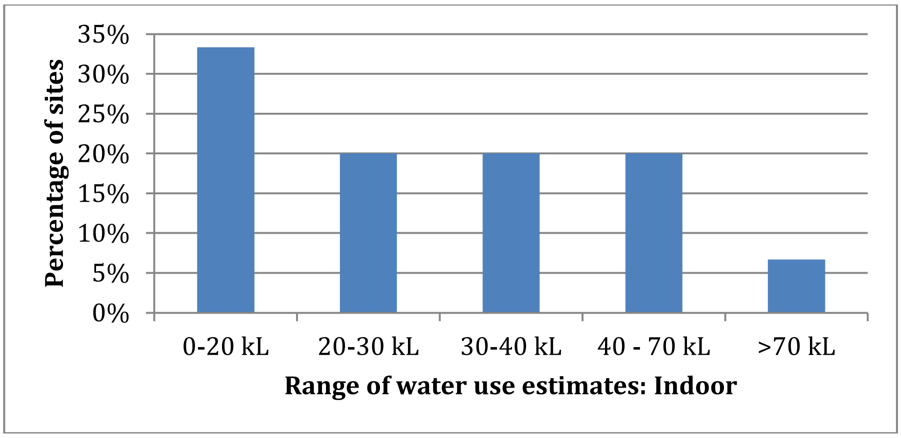



Figure 112: Histogram of indoor water use (potential)

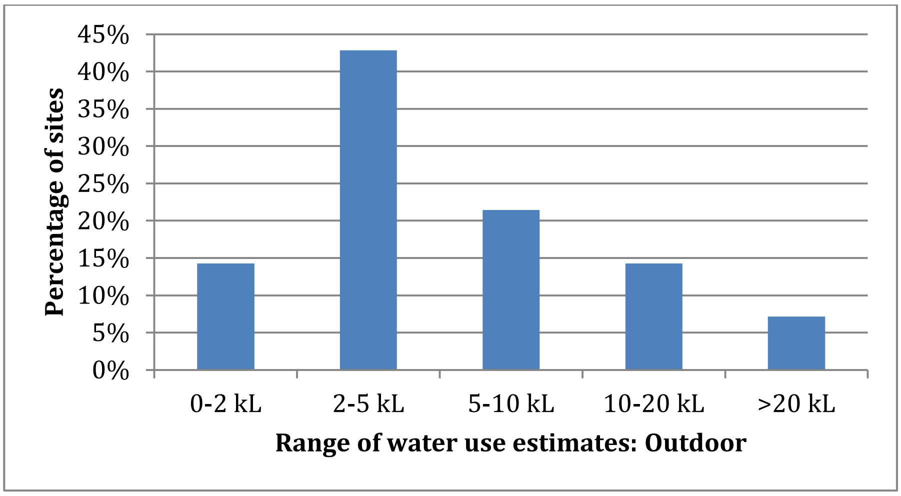



**Figure 113: Histogram of outdoor water use (potential)**

**Table 56: Rainfall and rainwater use**

| Site ID | Category | Annual rainfall (mm) | Rainwater use indoor (kL) | Rainwater use outdoor (kL) | Nearest weather station* |
|---|---|---|---|---|---|
| 1 | Indoor only | 993 | 26.0 | - | 86104 |
| 2 | Indoor only | 770 | 59.0 | - | 86074 |
| 3 | External only | 622 | - | 2.4 | 86210 |
| 4 | External only | 790 | - | 48.0 | 86079 |
| 5 | Indoor and outdoor | 616 | 37.9 | 1.1 | 86096 |
| 6 | Indoor and outdoor | 554 | 32.6 | 6.0 | 86039 |
| 7 | External only | 975 | - | 3.2 | 86299 |
| 8 | Indoor only | 770 | 20.2 | - | 86074 |
| 9 | Indoor and outdoor | 536 | 33.6 | 7.1 | 86039 |
| 10 | Indoor and outdoor | 557 | 25.6 | 10.0 | 86039 |
| 11 | Indoor and outdoor | 785 | 61.1 | 2.5 | 86104 |
| 12 | Indoor and outdoor | 950 | 14.6 | 0.0 | 86299 |
| 13 | Indoor and outdoor | 576 | 45.6 | 1.1 | 86020 |
| 14 | External only | 616 | - | 4.9 | 86096 |
| 15 | Indoor only | 565 | 22.5 | - | 86038 |
| 16 | Indoor and outdoor | 837 | 9.9 | 14.4 | 86244 |
| 17 | Indoor and outdoor | 770 | 127.8 | 19.6 | 86074 |
| 18 | Indoor and outdoor | 790 | 10.3 | 0.0 | 86079 |
| 19 | Indoor and outdoor | 576 | 7.2 | 0.0 | 86020 |
| 20 | External only | 557 | - | 5.0 | 86039 |
| 21 | External only | 519 | - | 2.9 | 86035 |
| **Average** | **All** | **701** | **35.3** | **7.5-9.2*** ** | **N/A** |

*Note: This information is collected from the Bureau of Meteorology website: http://www.bom.gov.au/

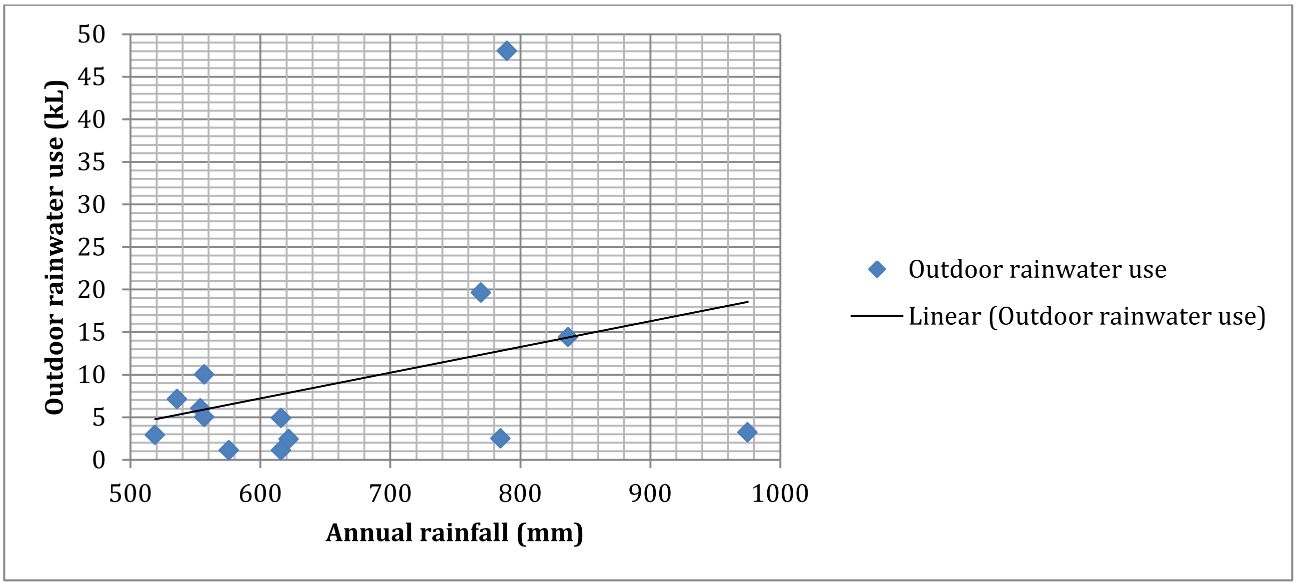



**Figure 114: Relationship between annual rainfall and outdoor rainwater use**

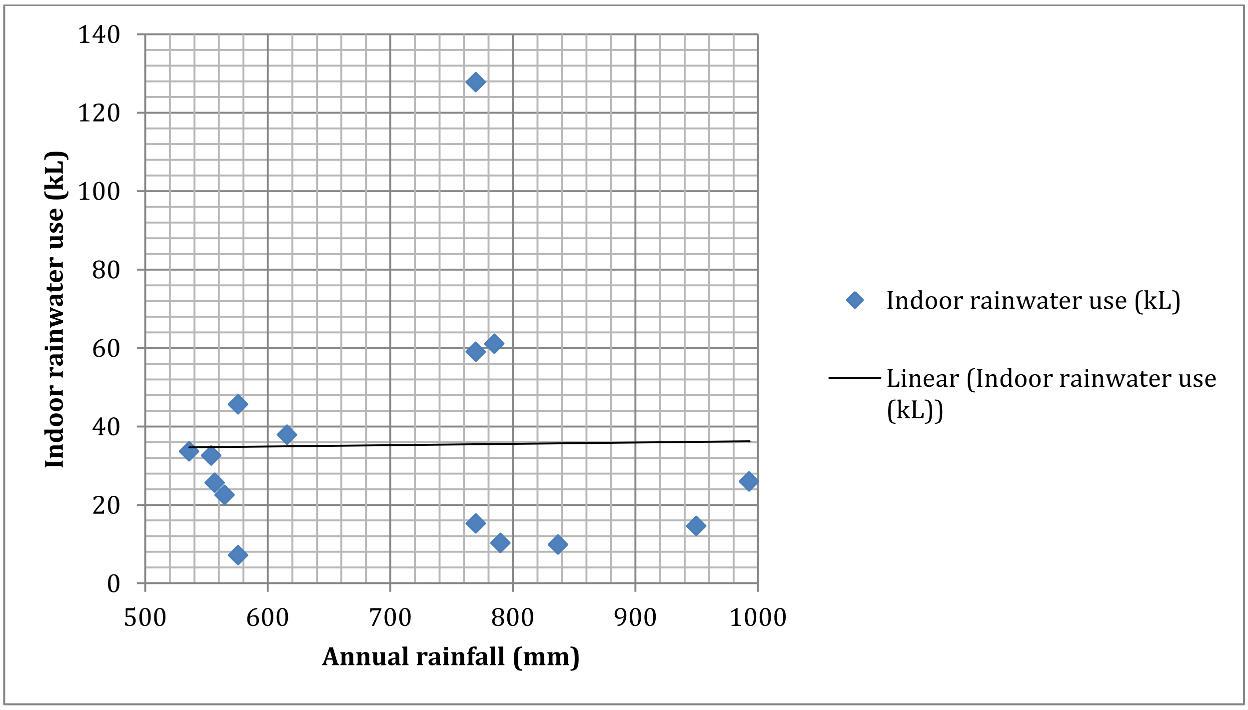



**Figure 115: Relationship between annual rainfall and indoor rainwater use.**

## 5.5. Qualitative case study of high achieving site

The household in site 17 stands out as having achieved very significant water savings from their rainwater tank in comparison to other sites. In fact, from a mere volumetric perspective this is best practice in our study and therefore the householder experiences and views from this site have been explored in further detail. Below is an extract, written by the participant, to describe the experience and practice of this household in regards to their rainwater tank system.

> *We rebuilt our house in 2009 and chose to use a sustainability architect to deliver a more sustainable home. Key features of the sustainable home includes double glazed windows, extra*

*insulation, northern aspect for all our living area, solar panels, a greywater system and rainwater tanks.*

*The rainwater tank system supplies water to all but three cold water taps in the house. They are the taps in the kitchen, and two bathrooms, essentially supplying water for everything but drinking and cooking. We selected a stainless steel hot water tank as rainwater can be a little more acidic than reticulated water, and a standard copper hot water system can corrode quicker in higher acidic water in some instances. Two filters are used, a 20 micron one followed by a 1 micron one. The filters were installed because our water goes to our hot water system and washing machine, and we wanted to provide the greatest protection to these against fine particulate matter. The total tank capacity is 18 KL. The tanks are placed at one side of the house, fitted using slimline tanks. In considering tank capacity we analysed the average monthly yield and demand, and then had to choose how many 6 KL tanks to install. We chose 3 tanks with a total capacity of 18 KL to give us the best yield for cost. This decision was made on the basis that increasing the capacity to 24KL would have only increased the security from about 80% to 85%.*

*The tanks have reduced our reliance on the reticulated water supply system significantly. So from a sustainability perspective, we are very satisfied, and recommend anyone with similar aspirations that significant gains can be achieved. We have never had a water colour problem, and only in a unique situation do we have odour problems. This occurs at times we are not using the system for two or more weeks, typically in summer, and when we return from holidays the water can have a musty smell similar to that of stagnant river water. This issue was rectified with the dosing of a commercial 'water purifier' product.*

*While we are very happy with the water savings achieved it certainly hasn't been plain sailing. So much so, that all the things that have gone wrong have essentially doubled our costs. Therefore, we feel that caution needs to be taken and we feel compelled to retell some of our less than ideal experiences in the hope that they could help others. These experiences concern the design from a sustainability architect, the plumbing installation, as well as the landscaping works.*

*The sustainability architect who planned the systems boasted 20 years' experience, and we thought he would be suitably skilled to design the appropriate configuration. However, we found that their enthusiasm exceeded their practical skills. Firstly, they devised a complicated limestone filtration system that the plumbers could not source, and on further investigation no other person thought necessary. They did not appreciate the need for a special foundation to take the load of three 6,000 L tanks, which equates to 18 tonnes when full, and undue settlement occurred. The tanks had to be emptied, removed, and the foundation had to be rebuilt at a later stage. Not only that, the second foundation has now also had significant settlement, and we are currently planning further rectification.*

*Also, the plumber installing the system did not include the filters, as were specified. In addition, the builder and sustainability architect, who were managing the project, did not notice that such filters had not been included. These filters then had to be installed at a later stage, adding more cost than was necessary.*

*The landscaper also added unnecessary costs by interconnecting an agricultural drainage pipeline to the downpipes, which was designed to collect water and convey this to the rainwater tanks. Unfortunately, such a downpipe system is different to a normal drainage network, as it* *needs to operate under pressure for the water to flow via gravity from all downpipes into the rainwater tanks. As a consequence, when it next rained; our new house flooded inundating three rooms and destroying the carpet and floorboard in three rooms.*

*In conclusion, we are happy with the reduction in potable water supply use that we have been able to achieve, and this has fulfilled our sustainability expectations. In our particular situation however, we have had to incur additional burdens in fixing problems, which should be avoidable with appropriate knowledge. That taints our view on the experience. Four years on from installing our rainwater tank system, while we are proud of what we have achieved, our household still debates whether the sustainability achievements were worth the effort and cost.*

This case study shows two important points: 1) rainwater tanks, if set up correctly, have considerable potential for contributing to urban water supplies, and 2) due to some significant risks to the household, it is important not to under-estimate the need for setting up systems correctly, especially in terms of adequate filters, foundation and drainage.

# 6. Discussion

This study has provided insights based on both the metering study as well as the condition survey study. This section provides some discussion about the results and lessons learnt.

## 6.1. Insights from the metering study

The rainwater use in the different sites varied considerably depending on the setup. External only sites (6 sites) had an average rainwater use of 11 kL per annum, but a significant contribution to the relatively higher value was an outlier; a semi-rural site with very high usage (48 kL) whilst the remaining other sites had an average usage of 3.7 kL. The 4 indoor only sites had an average rainwater use of 31 kL (in this case compensating for the reduced usage due to faulty switches) which varied between 15 kL and 59 kL. The sites where rainwater was used both for indoor and outdoor purposes had an average rainwater use of 42 kL after compensating for automatic switch malfunctions. If including the issues with switch malfunctions, the averages are 33 kL for indoor and outdoor sites, whilst it is 27 kL for indoor only sites. The impact of switch malfunctions is considerable.

Notable here is that the average rainwater use for the indoor only sites (31 kL) and the outdoor only sites (11 kL) exactly add up to the sites for which rainwater is used for both indoor and outdoor purposes (31+11=42 kL). This is likely to be primarily a coincidence, but what can be said is that it seems that the potential for rainwater usage is primarily demand driven in a year such as the one just past when rainfall is relatively plentiful. It is notable however that the outdoor component of rainwater use is somewhat dependent on summer rainfalls – but the outdoor component is relatively small compared to what is feasible for indoor rainwater use.

With approximately half of all tanks used only for outdoor purposes (note: this is likely to be an under-estimation if comparing with ABS figures which shows only about a third of tanks plumbed indoors), there is a potential 247,000 existing rainwater tanks that could be plumbed indoors and thus provide an additional average of 31 kL per annum; or approximately 7,700 ML per annum across the Melbourne Metropolitan area if all these tanks were plumbed indoors. This would be equivalent to approximately 2% of the Melbourne annual water demand[8]. The cost of connecting an existing rainwater tank for indoor and outdoor use is approximately $1,500. The cumulative cost of upgrading these tanks would thus be approximately $371 million or $48 million per GL (annualized). But with a rebate, the full cost is not carried by those responsible for water supply, but with householders co-investing, and thus with the assumption that the tank will be providing water for on average 10 years, and that the water suppliers would pay only for a third of the cost of the retrofit, the cost of the provided water is about $1.60/kL – without even taking into account any social or environmental benefits. Based on official figures, this would compare favorably with other options such as for example desalination; and could even compare with investment in dams. Thus, it could be argued that with the appropriate policy settings, a rebate to householders for such an upgrade could be a cost effective water supply supplement. The issue of course for water supplies is that they can't charge householders for this water. For the householder however the monetary savings from the reduction in mains water used would not justify the investment unless the tank was in use for at least 15-20 years. There are however other benefits for householders, such as providing an additional supply during water restrictions and to have backup water supply for times when it is needed; i.e. bushfires etc.

It is also noted that in four of the metered sites (19% of sites), automatic switches were either broken or turned off. The impact of this is that tank water demand was being met by mains water. For these sites, the average reduction in rainwater consumption is 29.1 kL per household (based on estimates of how much water was going through the automatic switch in these sites). It is also estimated from that inspection survey that approximately 27% of all rainwater tanks across Melbourne Metropolitan area have automatic switches and that approximately 35% of those are non-operational. This means that for the rainwater tank population, 2.7 kL (0.35*0.27*29.1) less rainwater is used than otherwise would be possible per average tank (i.e. the estimated statistical average of the rainwater use loss). With recent estimates of number of rainwater tanks in Melbourne (31% of households as per ABS[9]) combined with an estimate of total number of households in Melbourne at approximately 1.6 million, there should be approximately 494,000 rainwater tanks in Melbourne. With these basic estimates, the opportunity for approximately 1,330 ML per annum of potential rainwater use is being lost due to faulty automatic switches. In most of these cases, the same amount of mains water would be used. With a modest $2 per kL price of mains water, the broken automatic switches incur an annual cost of $2.7 million to the Melbourne Metropolitan community. There should be significant opportunities for efficiencies if the rate of failure of these switches could be reduced.

It is also noteworthy that some participants also noted pump problems occurring during the metering periods, and that this is another potential cause for under-utilization of the rainwater tanks. It is also worth noting that whilst these issues are relating to private properties, there are a number of ways that water companies can work with rainwater tank owners to ensure the condition is being upheld, as per report on rainwater tank management based on expert consultation, stakeholder interviews and community forums (Moglia et al., 2013b).

## 6.2. Energy use

The specific energy use in the various metered sites varied in the range between 0.7 and 4.2 kWh/kL and with another, outlier, site where water appears to be extracted without using the pump (i.e.

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[8] This is based on Melbourne Water's estimate of Melbourne's total demand in 2011-212 at 360 GL per annum.

[9] http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4602.0.55.003main+features4Mar%202013

specific energy is 0 kWh/kL). The average specific energy was 1.7 kWh/kL; a value which is aligned with expectations and in line with the range of 0.9-4.9 kWh/kL and an average of 1.5 kWh/kL found by Retamal et al (2009) and the range of 0.6-5.3 kWh/kL found by Tjandraatmadja et al (2011). The empirical probability density function is shown in Figure 116. This shows that there are essentially two separate distributions of specific energies; the lower value population (75% of the sample) has what seems like a *Normal* distribution of values with an average of 1.25 kWh/kL and the higher range population (25% of the sample) has what seems like a *Normal* distribution of values with an average of 3.3 kWh/kL. It is unknown what may lie behind the presence of these two sub-populations but this may be worth further investigation. For an extensive review on the variability of energy use in rainwater tank systems, see Vieira et al (2014) and for exploration of the factors contributing to high energy use, see Tjandraatmadja et al (2011). Likely factors contributing to energy use variability are: water flow patterns, water depth in the tank at the time of use, the use of pressure vessels, the amount of energy expended in standby-mode, and pump efficiency. Detailed analysis of the reasons for specific energy variability is not part of the scope of this project; nonetheless further analysis is being undertaken by a student from KTH in Sweden into this issue.

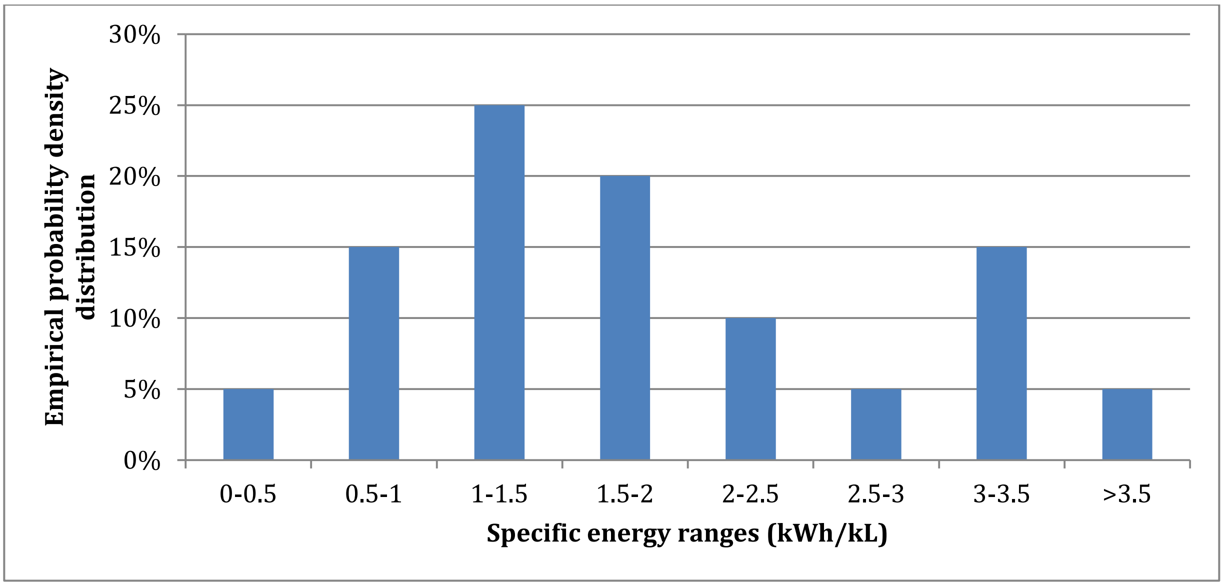


**Figure 116: Empirical probability density function for specific energy values**

## 6.3. Lessons for future metering studies

The metering study has been useful as a learning experience and in future studies a number of improvements could be made. It may also be possible to explore additional questions.

**Non-metered usage**: Flow meters have the limitation that, depending on how the flow meters have been set up, it may be possible to extract water from a rainwater tank without it registering as water use. In this study it was found that flow meters combined with energy meters and depth gauge measurements provide a more complete picture of the water use.

**Validation of depth gauge estimates**: Estimates of water use based on depth gauge measurements involves the potential for errors to be made because: 1) there is an error margin in any given measurement (about +/- 1mm in this study); 2) there is some level of any uncertainty in the estimated base area of the tank which is a required parameter for water use estimation, 2) there would be evaporation from rainwater tanks, causing a slow rate of decline in the water level and it would be difficult to distinguish this from legitimate water use, and 3) it would be impossible to get an accurate measurement of water use that coincide with rainfall events. It is recommended that to be able to use depth gauge measurements to get accurate estimates of rainwater use, that flow meters and depth gauges be set up to calibrate the water use estimation parameters to maximize the capacity for water use estimate. A key parameter is the time step from which depth differences are being estimated. It would also be critical to find improved ways to estimate the base area of the tank. In this study, the base area was estimated based on height and volume of the tank or the manual measurements of other tank dimensions. An improved method would be to estimate the base area based on calibrated depth gauge measurements, and the change in depth of water in response to adding a known volume of water (say for example exactly 10 liters of water). This is also in acknowledgment of reported discrepancies between estimated and manufacturers tank volumes (Biermann et al., 2012).

**The impact of multiple tanks**: The presence or absence of inter-connected multiple tanks in a site should be considered in the study design because it appears that sites with multiple inter-connected tanks have in a number of cases out-performed single tank systems. This is likely to be due to the larger water storage potential, the practicalities for designing a larger capture area, as well as the flexibility in moving water from one tank to another.

**Ongoing checks of results**: It was found that whilst there were automatic checks of the results streaming onto servers from the flow meters, there was a need for some manual or at least more intelligent checks to ensure that faults could be handled quickly. These types of checks need to occur on a regular basis: 1) warnings for non-zero logging of data from each meter (noting that logging of "zero" values often is not representing faulty data); 2) checking for correlations of meters that ought to be correlated (for example pump energy and tank water use; or automatic switch and mains water); 3) checking for correlations of water use estimates based on depth gauge data and based on flow meter data.

## 6.4. Insights from the configuration and condition of rainwater systems in Melbourne

A survey of 417residential rainwater tanks across Melbourne was conducted across Melbourne. It is noted that the survey has some bias towards tank owners with an interest in their tank, which tends to mean relatively larger tanks and tank to a greater extent plumbed for indoor purposes.

The majority of the inspected tanks (62%) were installed between 2007-2010 during the peak of the drought and the severe water restrictions levels. Examination of the role of incentives on tank uptake has shown that in the available data set, houses with 5-star sustainability rating for new homes is relatively poorly represented in terms of survey participation – only 20% of tanks fell under that category. Behind this lies the fact that recruitment efforts in areas with new housing, for various reasons, had relatively poor success rates; and not many houses with the 5-star sustainability rating appeared in areas with relatively older housing. Rebated tanks comprised 37% of the sample, 57% were not rebated. Thus this shows that many of the tanks were independently installed by the home owners due to other drivers.

Majority of participating home owners installed a single tank (57%). But 25% installed 2 tanks and the remainder 17% of the population installed 3 or more tanks. Tanks volume varied, but 49% were small tanks <3kL, 23% were between 3 to 5kL and 11% were bigger (>5kL), with a few examples of more than 20kL.

The polyethylene tanks were the most popular type (76%), which was expected as they often are the least expensive. However, there was an almost equal split between round and slimline tanks

(51%:41%), and tanks were predominantly above ground (94%), which would make access and inspection easier.

Screen guards, mosquito meshing and pumps were the main ancillaries installed with tanks and observed respectively in 92%, 91% and 86% of tanks. Mosquito meshing is a standard feature in most of tanks in the market; however 8% of tanks had no meshing. However non-standard devices (leaf guards, first flush devices and gutter protectors) were less common (less than 10% of sample). Signage was only seen in 26% of dwellings.

Automatic mains water switches were adopted in 25% of households, with the rest adopting manual switches. Unfortunately, there was a significant failure rate for automatic mains water switches, 52% failed and 35% were not operational at the time of inspection.

The type of switches may be also linked to the end uses types, as an equal split was observed between sites with indoor and outdoor only connection (51% : 49%). However as expected, regulated tanks were mostly connected to indoor uses (94%), whilst indoor connection was discretionary for rebated tanks (68%).

Majority of the inspected tanks were self-standing, 51% of tanks were on level foundations, 42% were on unleveled foundations but were stable and 6% were on hazardous foundations. Of greater concern was that 13% of tanks were leaning against a structure.

Among indoor uses, vast majority were non-potable. Toilet flushing was widely adopted (94%) of indoor connections, followed by washing machine and the cold laundry tap at 50% and 28%. Yet, 14% of dwelling adopted rainwater for hot water and shower and 9% for drinking and cooking.

Majority of the tanks (98%) were in good or fair condition and 90.3% had pumps that operated properly. However, the integrity of the pipe work connected to the tank was difficult to assess: 49% were properly connected, but 40% were unable to be inspected. Tank overflows were in good condition in 87% of tanks, but the remainder 13% were in poor state or had no overflow installed, which could lead to base erosion. Leaks were also uncommon, with only 9% displaying leaks.

Analysis of pump history showed that 63% still had the original pump unit supplied with the tank, but 12% has experienced pump failure in the past, 5% were not operational and 1% had decided to remove the pump. However, 18% of pumps tested showed leakage, yet noise issues were minor (only 3%).

Examination of gutters showed that majority, 92%, were in good condition, 5% were in average condition and only 2% were blocked. Despite the lack of gutter guards, about 66% of dwellings had minimal debris in the gutters, but 19% and 12% had gutters that were respectively half or completely filled with debris.

Only 8.4% and 9.8% of dwellings installed first flush diverters and leaf guards on their systems, respectively. However lack of maintenance was evident for such devices as 51% of first flush devices were blocked.

Water characteristics were generally aesthetically pleasing. Sediment in rainwater was low for 67% of tanks, medium in 17% and high in 8%. However, 19% of tanks had odors emanating from them and 57% had some type of discoloration, which can be a deterrent for indoor uses such as clothes washing.

Health risks also need to be considered: mosquito larvae were detected in 12.5% of tanks and 39% of dwellings had lead flashing in their roofs, thus requiring further treatment in case of potable rainwater uses.

In summary, whilst many types of faults are too commonplace, the majority of tanks were in good condition, which may be correlated to the age of installation (<7 years for majority) and maintenance. However, not enough is known about maintenance practices. The type of ancillary devices observed suggests that most home owners adopted the standard tank system package offering by tank providers (tank with already installed guards and pumps).

## 6.5. Strategies for improving the condition of rainwater tanks

It was found in this study that there are indeed some concerns about the condition in which many rainwater tanks are kept. From a management perspective, a range of issues in rainwater tanks need to be considered.

**Poor installations**: for example issues with foundations of tanks, or the way that tanks have been set up with too small catchment area, or with not the correct devices. The key strategies for addressing such problems may be certification of inspections, or education of homeowners or training of professionals such as plumbers to improve the quality of installations. It was found that problematic foundations were installed by all types of installers (including builders) but issues were more common if it was a DIY installation or the tank system was installed by a plumber.

**Lemons**: problems due under-performing technical devices such as some automatic switches or some tank types. There are currently very few mechanisms for industry wide learning about what technical devices perform and which don't. This survey provides some data to inform this discussion, but another approach would be to keep a tank register combined with self-reporting by rainwater tank owners if they are aware of problems (for example on a rainwater tank owner website). With the knowledge about what works and what doesn't, it would be possible to have conversations with manufacturers about possible solutions, as well as to provide more transparency for buyers of tanks and technical devices.

**Need to develop maintenance awareness**: Majority if the tanks were in good condition. Despite this there are clearly some rainwater tank systems that are not well maintained, with tanks, gutters, piping and devices which are sometimes in poor condition. The data from this survey can be analysed to gain some understanding into the psychological factors that increase the likelihood of householders maintaining their tanks. Whilst that type of analysis has not been completed in this project, preliminary analysis found that two factors are crucial: 1) providing the knowledge of what maintenance that is required (this increases the rate of maintenance up to nearly 2/3) and; 2) working to build householders' confidence in being able to undertake the maintenance themselves.

To inform this discussion, whilst formal analysis has not yet been undertaken, Figure 117 shows some preliminary results from analysis of the household survey data; showing that knowledge and confidence are the key factors that contribute to maintenance of tank systems. This table shows a synthesis of results from the household survey calculated using the Bayesian Network Netica software system. The table shows the empirical rates  percentages noting yes or no to the question of whether they undertake tank system maintenance) of self-reported maintenance correlated with the response to whether householders expressed that they have the confidence and/or knowledge to maintain their systems; and whether they perceive any benefits with their rainwater tank systems. It is pretty clear that confidence and maintenance knowledge is critical in their influence of self-reported maintenance of tanks but perceived benefits of their tank systems is not.

| Confidence | MaintenanceKnowledge | PerceivedBenefits | Yes | No |
|---|---|---|---|---|
| Yes | Yes | Significant | 88.388 | 11.612 |
| Yes | Yes | Limited | 95.249 | 4.751 |
| Yes | No | Significant | 0.0998 | 99.9 |
| Yes | No | Limited | 0.131 | 99.869 |
| No | Yes | Significant | 66.556 | 33.444 |
| No | Yes | Limited | 66 | 34 |
| No | No | Significant | 0.102 | 99.898 |
| No | No | Limited | 0.111 | 99.889 |

**Figure 117: Conditional Probability Table from Netica showing rates of self-reported maintenance for different combinations of responses to whether participants have the confidence to undertake maintenance, whether they have knowledge of what tank system maintenance is necessary; and whether they perceive there to be private benefits of their tank systems.**

**Not enough information for planners**: Given that the problems of rainwater tanks are real and commonplace, it will be important for government departments to manage the health risks of poorly maintained tanks, as well as for water planners to ensure that water savings can be maintained over time. This is particularly pertinent if as many as 9% of tank owners use rainwater for potable purposes. In order to ensure that this occurs over time, planners and public officials will need accurate data, which can only be collected through surveys such as these. These surveys should form the basis of an adaptive management plan for rainwater tanks, where strategies for addressing the above issues are put in place, and the efficacy of such strategies monitored through surveys like this one.

**Trust:** Interestingly, it was found that there was a common sense of distrust of government and water companies when it comes to rainwater tanks. A common conception was that governments or water companies will soon charge rainwater tank owners for using their tanks. It was also a common idea that rainwater tanks are private property and there is no room for government interference. This poses challenges if rainwater tanks are to be maintained and to allow these to keep delivering public benefits. Building a level of trust between water companies and rainwater tank owners will be a critical element of any rainwater tank management strategy.

## 6.6. Data issues

In many sites it was possible to undertake cross-validation by means of comparison of estimated rainwater use between those based on flow meter data and those based on depth gauge measurements. For most sites, there was strong similarity between estimates, but in occasional sites there were considerable differences, i.e. site 4. Small differences can be explained by a set of common measurement errors, but large differences can only be explained by one of two reasons: 1) either of the metering equipment was not functional, or 2) there may be ways of extracting water out of the tank that are not measured by the flow meter equipment. In the case of site 4, as equipment has been checked for functionality, the second explanation is likely to be the true. This shows a limitation of measurements of rainwater use by means of flow meters.

It is notable that in only 10 of the 21 sites was it possible to put flow meters to get readings on the total mains water supply into houses and even in a couple of these sites the existing mains meter was less than ideal to place a metering and recording device . This means that the ability to gauge the volumetric reliability in the sites is limited. It is also noted that in one site, the electricity meter was not functional. In two sites (8 and 12); the metering period stretched for less than 12 months.

### 6.7. Storing the data for further analysis

The data from inspections and the household survey has been recorded in an application on a tablet computer. The tablet computer application is called *Fulcrum* (http://fulcrumapp.com/) from which data has been uploaded on a server. The different data sets are:

- Inspection and household survey data. Sites are identified with a site ID but with no personal information except the GPS coordinates.
    - The household survey information is stored in a single table.
    - The inspection result data is stored in three different tables because of the need to add further questions at different times of the study.
- Flow meter, energy meter and depth gauge data for a number of sites
- Participation consent forms will be stored in a secure location.

## 7. Recommendations

Through the discussions, a number of recommendations were identified. Recommendations relating to improving the volume of water supplied from rainwater tanks are:

1) **Promoting that rainwater to a greater extent is used for indoor purposes has the potential to improve Melbourne's supply-demand balances in a seemingly cost-effective manner**. However, only rudimentary cost-benefit analysis has been undertaken, and further efforts are required in this area.
2) **When rainwater is used primarily for outdoor purposes, it is critical that a tank is connected to as large connected roof area as possible**. This way, the chances of running out of water during the summer, when water is usually needed, can be significantly reduced.
3) Noting the great difference between poorly performing and high achieving sites, there appears to be a significant potential for increasing the water savings potential from rainwater tanks. Further effort should go into understanding what allows high performing tank systems to achieve such high levels of water savings – so that the lessons learnt could be spread more widely to the community. In other words: **Further efforts are required in developing and promoting "Best Practice Guidelines" for rainwater harvesting in urban and private backyards**.

Based on our study we note that it is clear that **many concerns have emerged in regards to the adequacy of rainwater design, installation and general conditions**. There appears to be a need to improve community awareness of the need for looking after private tanks as well as further education of what maintenance is required. However, efforts need to go further than that and will need to include increasing the skills and capacity in relation to rainwater tanks of the plumbing profession as well as the building profession. Some of the most important issues that need to be addressed are:

- **Effort is required in trying to make sure that automatic mains switches do not fail to the relatively large extent that they currently do**. This effort will need to involve manufacturers, water industry as well as private tank owners to find practical and cheap solutions to the problem. Key activities may be:
    - ✓ Working with manufacturers to understand and deal with the root causes for why the automatic switches fail.

- ✓ Consider alternatives to automatic switches.
- ✓ Set up warning systems, using sensors, so that householders can be made aware when the automatic switches do not work adequately.

- **Foundations for rainwater tanks often have to hold relatively heavy loads, but unfortunately it has been found that they are frequently inadequately designed and/or installed; and this issue needs to be addressed**. Many have shown signs of not being even or at risk of causing damage, due to settling or foundation inadequacies. This poses a risk to community as well as property. We can't presuppose how to deal with the issue, it is up to stakeholders to decide, but solutions may involve further professional training, regulations, accreditation and/or mandatory post-installation inspections.
- **The extent of mosquito related health risk linked to rainwater tanks needs to be explored by relevant departments in order to ensure that adequate safeguards are in place to protect the community.** Rainwater tanks are often breeding grounds for mosquitoes; adding to the risk of spreading arbovirus in Metropolitan Melbourne.
- **Private tank owners need to be made aware of the need for maintenance, and to be educated on the type of maintenance activities that are required.** This is because the rate of self-reported knowledge of maintenance requirements in the tank owner community is inadequate. The self reported rate of maintenance activities is also inadequate but it is unclear what strategies may help to increase this. Research in South East Queensland has however identified some options that may help to improve this situation (Walton et al., 2012, Walton and Gardner, 2012, Moglia et al., 2013b).

Exactly how these issues are dealt with is not for us to presuppose. In fact, identifying practical and effective strategies require contributions from multiple stakeholders which can be generated in a research process such as that which has been undertaken in South East Queensland and which has involved a combination of expert and stakeholder interviews, industry workshops, community forums and household surveys. This process has been shown to be able to establish what appear to be workable solutions that could be agreed upon by most if not all stakeholders. As such we recommend these follow up activities:

- **We recommend undertaking industry and community consultation activities in order to establish workable strategies for addressing the rainwater tank problems**. Computational models such as, Bayesian Belief Networks can act to synthesize multiple judgments into a logically coherent collective assessment. However it is also noted that there will always be remaining inherent uncertainty in terms of the effectiveness of strategies. Therefore, implementation of strategies will need to be combined within an adaptive learning strategy.
- **We recommend that an adaptive learning strategy is implemented** which is based on a structured approach to strategy implementation that sets up natural experiments where the impact of strategies is being assessed using condition surveys such as the one described in this report. It is recommended that trained and certified surveyors are being used for this purpose to ensure consistency and accuracy in judgments.

Finally, we also note a common difficulty in rainwater tank related research and management, which is that it is often very difficult to identify specific types of rainwater tanks, or in fact to know which households have a rainwater tank. There is a privacy issue here, where rainwater tank owners are entitled not to share their information, but **it is recommended that a strategy is developed**

**whereby rainwater tank owners may share this information in a way that they are comfortable with**; for the purpose of furthering the knowledge about urban rainwater tanks in Australia.

Finally, **we also recommend that the data set that has been collected be utilized in a more complete manner**. The analysis that has been provided is rudimentary and many more conclusions can be made regarding issues such as impacts on stormwater run-off or what contributes to low specific energies. The data should also be analysed in order to understand the causes and factors that contribute to ensuring rainwater tanks are kept in an adequate condition.

# 8. Conclusions

This study has provided insights into the real world performance of rainwater tanks. It has helped provide some reference points in understanding what can be expected both in terms of tank system conditions as well as in terms of the water savings that can be achieved.

In terms of water savings from rainwater tanks, the average annual value was 31 kL for the indoor only sites and 11 kL the outdoor only sites and 42 kL in sites where rainwater was used for both purposes based on sample of 20 tanks. The specific energy for the sites varied in the range 0.7-4.2 kWh/kL. The average specific energy was 1.7 kWh/kL with two sub-populations.

A major finding of the study based on the inspection of 417 tanks was that faulty automatic switches in many cases are causing some significant reductions in water savings potentials. Faulty switches tend to mean that mains water is used to meet tank water demand although rainwater may be in the tank; leading to an average loss of 29 kL in water savings per household. About 40% of all houses had some type of mains switch to allow mains water to be used so that tank water demand is met by mains water when the tank is empty. In fact one quarter of all inspected sites had an electronic diverter; and about a third of these were faulty (i.e. one twelfth of all sites had faulty electronic diverters). Dealing with problems with automatic switches has significant potential for increasing the water savings potential of rainwater tanks.

There are some concerns about health risks to the community based on reports of inadequately set up or maintained rainwater tank systems. A key issue is that most foundations of rainwater tanks are not level and some are in fact dangerous; 13% of tanks were leaning against a structure such as a wall or fence, thus adding increased lateral strain resulting in cracks in rain tanks. Another serious issue is that in about a quarter of tanks, mosquitoes can enter and exit the tank; thus significantly increasing the risk of arbovirus related outbreaks of disease across the Melbourne Metropolitan area. Whilst serious water quality testing has not been undertaken, it was also found 57% of tanks had discolored water and 19% had odorous water whilst 6% of tanks had high concentrations of sediment. This indicates that water is often polluted, reinforcing results from previous testing in other parts of Australia, which has shown common presence of pathogens in the water. Whilst this is usually not a concern if the water is used for non-potable uses, poor aesthetics could discourage householders from using rainwater indoors for applications such as laundry, washing and toilets. On the other hand, dwellings that use rainwater for potable applications would require further pre-treatment prior to consumption and potentially owners may be encouraged to undertake more frequent maintenance; although this was not tested.

Finally, the results from this study reinforce the need for considering new ways to manage rainwater tanks. Rainwater tanks provide both private and public benefits but are mostly in private ownership.

Strategies for managing rainwater tanks need to consider improving the practice of tank system installation, improving the level of maintenance, weed out or improve technological lemons and build trust between water planners and rainwater tank owners. There is also a need for ongoing data collection on rainwater tank system performance so that effective industry and community learning can be achieved.

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# 10. Appendices

Appendices are provided separately to this report. The following are the headers of the Appendices:

A. Participation consent forms

B. Safe work instruction schedule for the site inspection program

C. Household survey questions

D. Proforma for site inspections

E. Proposed maintenance schedule for rainwater tanks

F. Pamphlets for recruitment of participants

G. Mapping of inspection sites against Metering participants

H. Participant characteristics

I. Flow metering set-ups