STUDY REPORT

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Residential Water End Use Literature Survey

Matthias Heinrich

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Preface

This report provides a summary of the technologies available for monitoring residential water end use. It provides an overview of :

- the suitable metering and measuring equipment
- findings from international research and monitoring projects/case studies.

The information reported is the first stage of a research programme to develop a methodology for monitoring water end-use in New Zealand houses.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended primarily for councils, government agencies, water suppliers and others researching and wanting to measure end use water consumption.

RESIDENTIAL WATER END USE LITERATURE SURVEY

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Matthias Heinrich

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ABSTRACT

This report is a summary of methods that are available to measure the end use consumption of water in residential buildings. A method, which has been developed over the last couple of years for this type of monitoring – flow trace analysis – is explained within this document. Case studies from different parts of the world and different types of measuring equipment are also addressed.

KEYWORDS

Water, end use, flow trace analysis, meter, consumption , data logging.

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RESIDENTIAL WATER END USE LITERATURE SURVEY

1. CLIENT

BRANZ Inc
Private Bag 50-908
Porirua
Wellington
New Zealand

2. INTRODUCTION

New Zealand is beginning to realise the finite nature of its reticulated freshwater supply, as evidenced by a number of initiatives occurring at central and local government levels. Due to the increasing number of drought conditions in some areas of the country, water shortages have raised awareness of the issue with the public. Measures such as sprinkler bans have been put into action to reduce the pressure on the available water resources. An example of areas experiencing these conditions is the Kapiti Coast, where the available freshwater resources are limited. Population increase and increased pollution levels add additional strain on the resource.

In addition to the straightforward benefits expected from conserving water, there are also substantial energy savings to be made. Early EECA information estimates that approximately half the cost of a delivered litre of potable water is due to the energy used to filter, treat and pump it to its end use. It is necessary to act now to use fresh water in a sustainable way and reduce the amount of avoidable wastage. According to the Ministry of Health a total of 300 litres of water per capita per day (l/c/d) is required (Ministry of Health 2004). As it can be seen from Table 1, only a small amount of water needs to be biologically and chemically safe.

Table 1: Fresh water requirements (Source: Ministry of Health 2004)

Source	Requirements	l/c/day
Drinking	Biologically & chemically safe	2
Cooking	Biologically & chemically safe	2
Food preparation	Biologically & chemically safe	1
Showering	Biologically safe	100
Toilet/clothes washer	Not discoloured & stain causing	145
General use	No requirements	50
TOTAL		**300**

In many parts of the country a much greater proportion of water is used. With the Water End Use and Efficiency Project (WEEP) we are trying to identify the volumes of water used in the households by each type of end use. End uses can include the following:

- shower
- toilet
- bath
- clothes washer
- dishwasher
- tap[i] (faucet)
- irrigation
- cooling/humidification
- outdoors
- others …

We also want to know when an end use event occurs and its duration (e.g. how long the average shower is and the associated volume), as well as to capture the behaviour and social drivers that encourage the so often wasteful exploitation of the earth's most valuable resource. By educating the public and implementing water-efficient fixtures, a part of this wasted water can be saved.

The purpose of this literature survey is to report on international and national research projects in water end use monitoring. The main tool for capturing the information was the internet and contacts with other agencies and researchers who are working in this field.

3. CASE STUDIES – AROUND THE WORLD

Understanding the end uses of fresh water is in the interest of many different types of agencies including local councils, water works, Ministry of Health/Environment and others. In recent years, estimating was the only way to capture the end use data. As technology levels have improved in the last couple of years, and different methods of data collection are being developed, a more scientific approach can be adopted towards measuring the end uses. The case studies mentioned in this section show an overview of what has been done, and what data collection methods have been used worldwide.

The literature survey was commenced by searching the internet and consulting a wide range of sources on water end use and water-related subjects. Some authors were then contacted to talk about monitoring issues. Peter Mayer from Aquacraft Inc, a consultant water monitoring company in the United States as well as the makers of TraceWizard, was very helpful in advising on what type of monitoring equipment to use. Peter Roberts from Yarra Valley Water sent a detailed report of their project, and suggested some improvements on monitoring and advice on the equipment. During the literature survey, more than a dozen case studies were looked at. The key findings of the most relevant studies are highlighted in the section below.

3.1 United States

A lot of water end use analysis and technological development has been undertaken in the United States. Large-scale studies included more than 1,000 homes throughout the country. Section 3.1.1 addresses one of the largest studies.

3.1.1 American Water Works Association

Residential End Use of Water Study (REWS)

From 1996-1999, the American Water Works Association Research Foundation (AWWARF) within the AWWA conducted a study in 12 cities across the United States and two Canadian cities to determine how water is utilised around the house (AWWA 1997). They also developed forecast models for future water demand.

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[i] Point of use, since it cannot be identified for what end use the tap is being used. Hand washing would be an end use.

Special data loggers, Meter Master from Brainards (retail price US$2,495 per unit), were attached to the existing water meters in 1,188 single-family residences. These collected data at a 10 second interval for a total of four weeks (two weeks each in summer and winter). The collected data allowed the researchers to disaggregate the data into individual end use categories using a specifically designed software package called TraceWizard© developed by Aquacraft Inc. Additional data came from 6,000 conducted surveys and billing records of 12,000 households. There were no home visits to avoided not introducing serious sampling bias caused by studying a group of volunteers (AWWA 1997).

The study was not only concerned with the consumption and the actual end use data, but also with demographic factors that affect the use of water. These factors included household income level, number of teens/full-time working adults and others. The pie chart in Figure 1 shows a summary of the indoor uses. Section 4.4 explains the methodology of the flow trace analysis used in this and other studies.

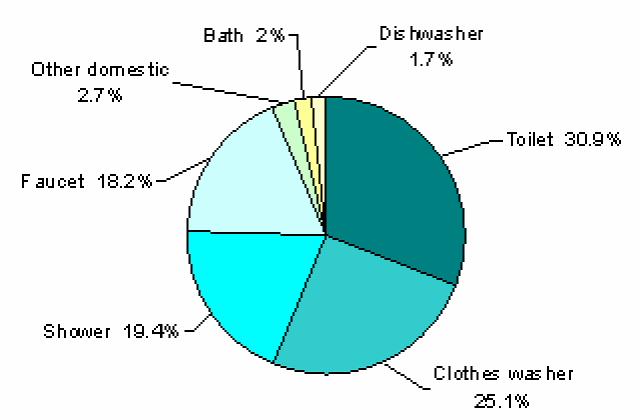


Figure 1: Summary of indoor end uses (Source: AWWA 1997)

Toilets were identified as the biggest users, with 30.9% of the total indoor water usage. This was followed by clothes washers and showers with a percentage of 25.1 and 19.4 respectively. The total tap (faucet) use was identified as 18.2%. The smallest proportion of water, 2%, was used in baths. The indoor water usage accounts for 42% of the total water usage, and the remaining 58% was used outdoors. The average daily per capita use was identified as 646.5 litres.

This study provides useful information, especially since it has been the largest of its kind. It showed that using the method of flow trace analysis, a large sample of houses can be monitored effectively. As one of the first large-scale studies using this method, it provides a valuable insight into what the potential is.

3.1.2 Tampa Water Department

Residential Water Conservation Study (2004)

This study (DeOreo et al 2004a) talks about the impacts of high efficiency plumbing fixture retrofits in single family homes. Monitoring of water end uses using the flow trace analysis technique was undertaken for two week periods before and after installation of water-efficient fixtures in 26 homes. This full report contains useful information on site visits, audits and data collection. The analysis of the results is in great detail. After the retrofit, the average household consumption dropped by 46%, from 769 litres per person per day (l/p/d) to 405 l/p/d. The full report is available from the Tampa City Council.

3.2 Australia

Due to increasing droughts and water shortages in parts of Australia, water companies and councils have invested in monitoring water end use to see how water is actually used and where major savings can be achieved. The case studies in this section were selected, since it is important to know what our neighbours have done in this area as well as to develop research networks to assist the project.

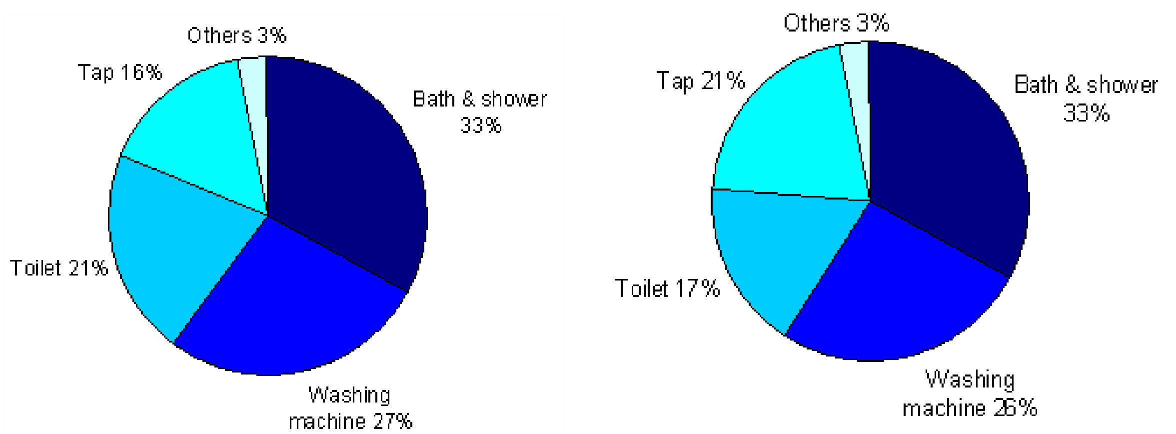
3.2.1 Water Corporation Western Australia

Domestic Water Use Study (DWUS) – PERTH (1997-2000)

The main objectives of the DWUS (Loh 2003) were to collect data on household water usage and to identify the water use patterns and trends. Another reason was to develop a demand forecasting model for the area as well as implementing a water use efficiency program at a later stage.

The pilot group included 120 houses, which were monitored from November 1998 to June 2000 (20 months) using the Meter Master technique and the TraceWizard© disaggregation software. From another group of 600 houses, the total monthly water consumption was recorded from November 1998 to February 2000. All 720 households completed three questionnaire surveys covering appliance ownership, attitude to water use and demographics.

In the second phase of the project, data was collected from 297 multi-residential households. A group of 124 households had metering equipment installed. Continuous monitoring was undertaken from September 2000 to November 2001. An additional group of 173 households provided questionnaire data only. The summary of the findings is given in Figure 2 below.



Single-residential Multi-residential

Figure 2: Summary of results (Source: Water Corporation Western Australia – Loh 2003)

The individual appliance usage and the per capita usage are shown in Table 2.

Table 2: Summary of results (Source: Water Corporation Western Australia – Loh 2003)

	Single-residential		Multi-residential	
Appliance	**l/house/day**	**l/capita/day**	**l/house/day**	**l/capita/day**
Bath and shower	171	51	121	55
Washing machine	139	42	94	43
Toilet	112	33	62	28
Tap	83	24	77	35
Other	18	5	11	5
Total in-house	**523**	**155**	**365**	**166**
Total ex-house	**707**	**210**	**389**	**177**
Leaks	29	9	14	6
TOTAL	**1259**	**374**	**768**	**349**

A more detailed description of the study can be found in the DWUS report (Loh 2003) available from Perth Water.

A similar end use study was undertaken in the same area in 1981/82, where the occupants were given diaries to record their water usage. Figures obtained from this period were then compared to the findings of the year 2000 study and the overall water consumption showed a similar result. This method is very intrusive, however, and volumes are often significantly underestimated (Cordell et al 2002) because participants are likely to change their behaviour due to knowledge that their actions are being monitored. This is known as the Hawthorne Effect and is further explained in Section 3.4.

3.2.2 Yarra Valley Water

2004 Residential End Use Measurement Study

In this detailed study (Roberts 2005), 100 homes were equipped with high resolution water meters and data loggers to collect water usage data at a five second interval for two weeks each in summer and winter. The software package TraceWizard© was again used to disaggregate the collected data into its end uses. Extensive use was made from survey and historic billing data. The results are given in Figure 3 below.

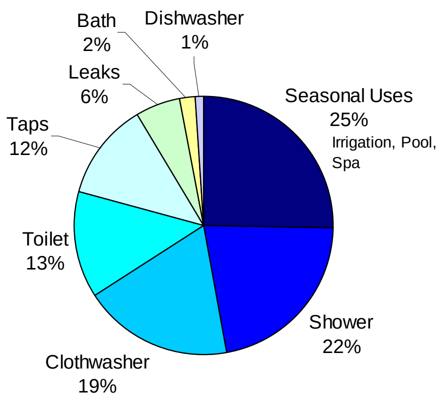


Figure 3: Summary of results (Source: Yarra Valley Water – Roberts 2005)

The largest end use was identified as the shower, with 22% of the total usage, followed by clothes washer and toilet, with 19% and 13% respectively. Seasonal uses accounted for 25%.

Peter Roberts, the demand forecasting manager of Yarra Valley Water and the project manager of the study, sent a full report and suggested some ideas to overcome the problems they had. He suggested weatherproofing each installation to counteract the problems of monitoring equipment corrosion which they were experiencing in their study. The report has a detailed record of the used methodologies, analysis and presentation of the findings. He also suggested the type of equipment to be used. He proposed to use a CT5-S positive displacement flow meter (ManuFlo) with a pulse output of 72.5 pulses per litre.

3.3 Canada

Another pioneer in water end use monitoring is Canada, where flow trace analysis tools (see Section 4.1) have been used. The following case study shows one of the early end use analyses using the flow trace methodology.

3.3.1 Toronto Water

In 1997, the City of Toronto monitored 24 households to determine water use and the effectiveness of water-efficient fixtures (City of Toronto 1997). The total household water use was disaggregated into component end uses. Other objectives included understanding the amount of water used for each event (i.e. toilet flush) and the frequency of use for each fixture. To minimise the intrusiveness and participation bias of the data collection method, a magnetic signal converter (data logger) was attached directly to the water meter. A software package was used to disaggregate the flow data into the various end use components.

Monitoring was undertaken for a total of two seven day periods one week before the installation of water-efficient fixtures and one week after. The results are shown in Table 3.

Table 3: Summary of results (Source: Toronto Water – City of Toronto 1997)

	Before replacement		After replacement		Savings	
End use	**share (%)**	**l/c/d**	**share (%)**	**l/c/d**	**share (%)**	**l/c/d**
Toilets	21.7	60.2	18.7	29	46.8	31.2
Showers	17.9	39.7	22.9	35.6	6.1	4.1
Baths	3	6.7	4.5	6.5	0.3	0.2
Clothes washer	14.4	31.9	20.1	31.3	0.9	0.6
Dishwasher/tap	18.2	40.5	23.9	37.1	5.1	3.4
Misc/leaks	14.5	32.2	8.1	12.7	29.3	19.5
Indoor totals	**95.1**	**211.2**	**98**	**152.3**	**88.5**	**58.9**
Hoses	44.9	10.9		2	11.5	7.7
TOTALS	**100**	**222.1**	**100**	**155.5**	**100**	**66.6**

Water demand dropped an average of 66.6 l/c/d after the water-efficient fixtures were installed. Before the retrofit, 60 l/c/d were used for toilet flushing after using water-efficient fixtures, and this volume dropped to 29 l/c/d. This 50% saving has a major impact on the total consumption. This study suggests that toilet retrofits are an effective way of reducing residential water consumption. The total volume of leaks was also substantially reduced.

3.4 Other case studies

- Extensive work in the water end use analysis has been conducted in North America, mainly by Aquacraft Inc using their tools and techniques. Their tools have almost become the standard measuring device for end use measurements. A detailed and useful report featuring the flow trace analysis method is the *End Use of Hot Water in Single Family Homes from Flow Trace Analysis* conducted by Aquacraft (DeOreo and Mayer 2000). This study will be further addressed in Section 3.5.

- A South African study by HE Jacobs and J Haarhoff (2004) uses a mathematical model to forecast the total use of water and the end uses. This study, however, is not relevant to our work since we want to develop a monitoring technique and not base our findings on a model.

- Studies have been conducted where water meters and data loggers have been installed at every end use appliance to collect the end use data. This system is very intrusive and only practical when a new house is being built. This technique can only be employed when monitoring a small sample of houses due to the efforts involved in installing the monitoring system and retrieving and processing the data.

- In a Princeton University study (Kempton 1986) residential water use was studied in seven houses as part of an energy study using electronic recorders and intensive interviewing. The intrusiveness of the data collection methods has precluded both large samples and random selection. Bathing was identified as the highest hot water use and the kitchen taps as the second highest.

The less intrusive the data collection method, the more representative the data becomes. When people know they are being monitored, and can see their actual consumption, they are more likely to change their behaviour (Hawthorne Effect). When being watched or monitored a person is likely to put on their best behaviour. Especially if they are a heavy water user, they think twice about watering their garden daily since other people can see what they are doing. The Hawthorn Effect has been mentioned in a number of water use studies, but there has been no evidence to suggest this effect is actually occurring. The study entitled *Outdoor Residential Water Reduction Programs – Do they Really Work?* (Bach 2000) sees the effect as a high priority when monitoring people for a water reduction program. It is not guaranteed that the Hawthorn Effect is actually occurring, but it should be taken into account.

3.5 Hot water systems

At the time of research, there were only a limited number of reports available which addressed the end use monitoring of hot water systems. *The End Use of Hot Water in Single Family Homes From Flow Trace Analysis* by Aquacraft (DeOreo and Mayer 2000) uses the smart metering arrangement mentioned in Section 4.1. The recording interval was set at a 15 second interval. One water meter and data logger was attached to the feed line of the hot water cylinder and another logger (10 second recording interval) to the existing outside meter in the metering pit. Two separate flow traces were recorded and analysed simultaneously. A total of 10 homes were monitored using this method as a part of the Seattle EPA study. After the monitoring period, water-efficient fixtures were installed in the homes to see what savings could be made in hot water use. It was found that the largest hot water use was the tap (34%), followed by showers (25%) and baths (16.7%). The collection of simultaneous flow traces provided accurate data on the hot water end use (DeOreo and Mayer 2000). The main meter flow trace was an immense help in disaggregating the hot water trace since the appliances responsible for the end use could be identified more easily.

3.6 Summary and comparison

After looking at several case studies, the most frequently used technique for monitoring end uses in the last couple of years has been the flow trace analysis technique. When wanting to monitor the end uses, without estimating the values, this is the only method used for a larger sample size. Table 4 shows a summary of the case studies and the results presented in this section.

As can be seen from the table, a substantial reduction of water use was achieved when installing water-efficient fixtures. The best example is the Tampa case study where consumption dropped by almost 50% (DeOreo et al 2004). The average indoor water use for the selected studies was around 190 l/p/d. The appliances that consume the majority of the indoor water are identified as toilets and showers.

In some studies the end uses were monitored for only two weeks, or even less. However, these studies considered historic billing data in their analysis. Since many residential homes throughout New Zealand are not metered (but they rather pay a fixed rate for water usage), this data is not available and WEEP needs to capture this. Auckland, Nelson and Tauranga councils are already metering households and charging according to usage. It is anticipated water metering will extend into other areas throughout New Zealand.

Table 4: Summary of results (synthesised by author)

Study	Number of houses	Monitoring time	Method	Highest indoor end use (%)	Average use l/c/day: Indoor	Average use l/c/day: Outdoor
AWWA	1088	2 weeks in summer	Flow trace analysis	Toilet (30.9%)	226.3	381.5
	1088	2 weeks in winter			-	-
Tampa	26	2 weeks before retrofit	Flow trace analysis	Toilet (23.2%)	293	N/A
	26	2 weeks after		Shower (23.5%)	148	N/A
Perth*	120	20 month	Flow trace analysis	Bath and shower (33%)	155	210
Yarra Valley	100	2 weeks in summer	Flow trace analysis	Shower (21.7%)	169	-
	100	2 weeks in winter			-	-
Toronto	24	7 days before retrofit	Flow trace analysis	Toilets (27%)	211.2	10.9
	24	7 days after	Flow trace analysis	Dishwasher/tap (23.9%)	152.3	2

*Single residential houses

Research suggests that monitoring should be undertaken in two periods, differentiating between summer and winter. This will be discussed further in Section 6. In between the two periods the total water consumption should be measured at an hourly or daily rate, since the equipment is already in place. This is to achieve additional information on the consumption rates and to obtain a database on hourly consumption patterns. Daily variations will also be discussed in Section 6.

4. DATA COLLECTION METHODS

There are different ways of collecting data for end use analysis. This section explores some of the available methods.

4.1 Smart metering arrangement – flow trace analysis

The flow trace analysis data collection method has proven to provide reliable results and has been used in many end use monitoring projects around the world. The 'smart metering' arrangement, consists of a data logger capable of picking up pulses at an interval of 10 seconds or less (15 second intervals have been used by measuring the hot water flows – DeOreo and Mayer 2000), which is connected to the output of a high resolution water meter. For hot water monitoring, due to the longer duration of these events this interval was adequate). A high resolution water meter is a flow measuring device that is capable of picking up more than 10 pulses per litre. These are available from about NZ$300, depending on the type of meter. A 10 second recording interval has demonstrated to be the best balance between the accuracy of the data and the storage capacity of the loggers (DeOreo and Mayer 2004b). The set-up is shown in Figure 4.

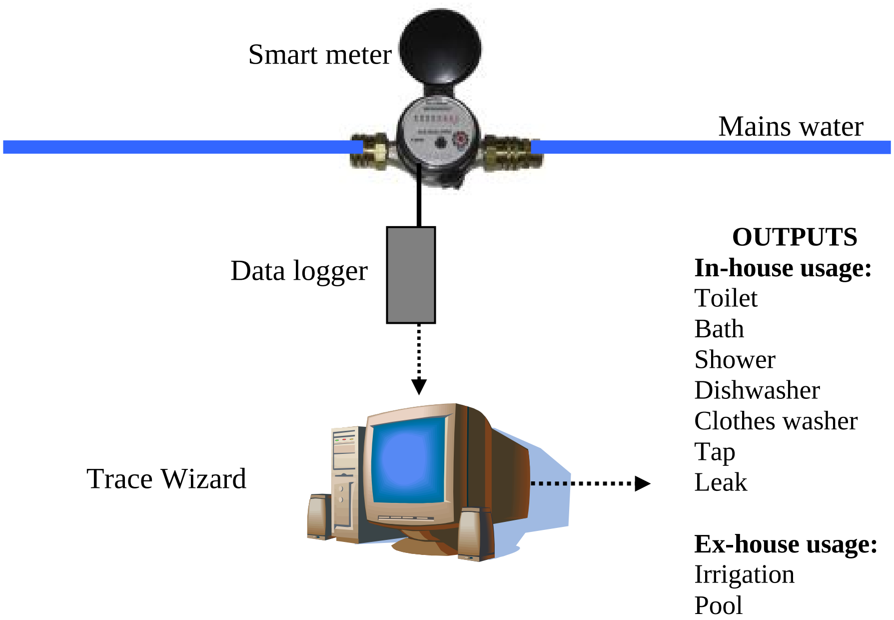


Figure 4: Metering arrangement

After the data has been collected, it is disaggregated using a software package called TraceWizard© designed by Aquacraft Inc. The program helps to identify where and when water is used, and how much. The diagram in Figure 5 shows an extract of the program.

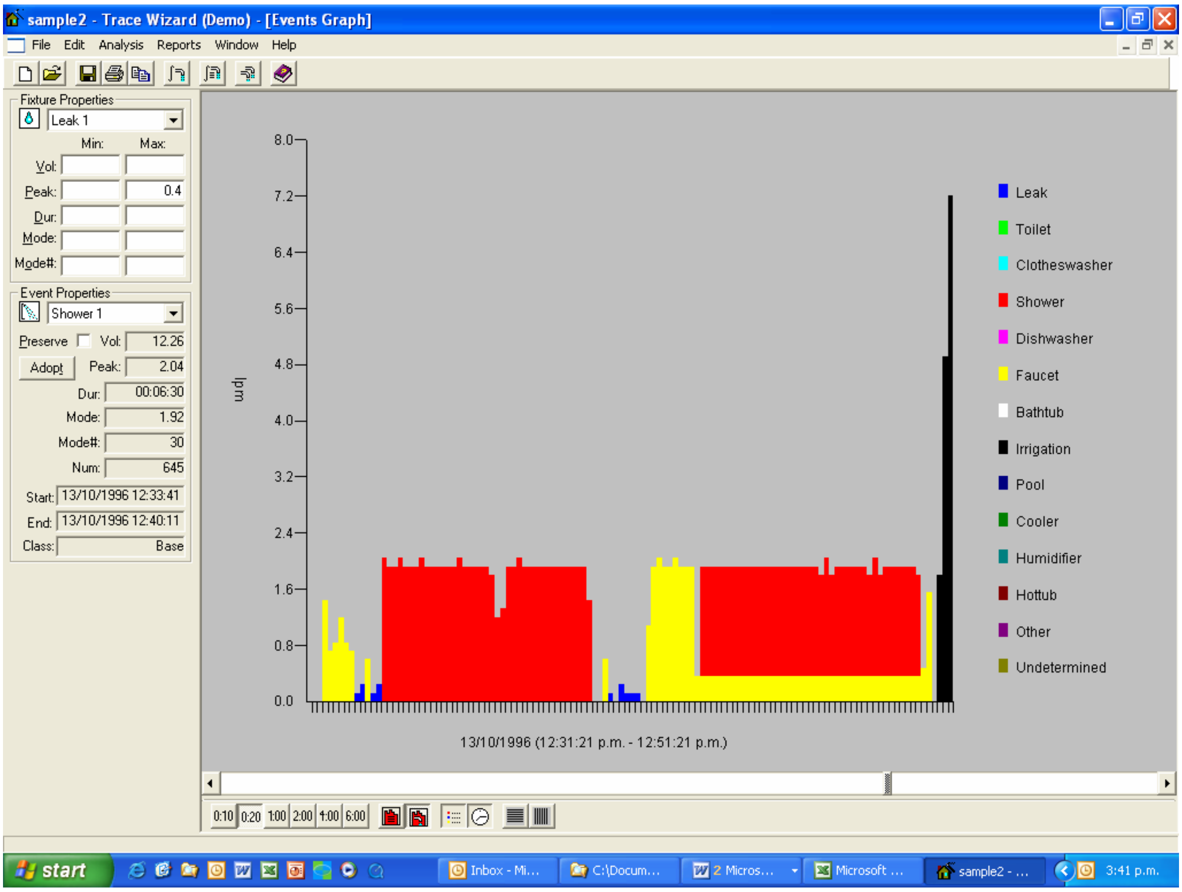


Figure 5: TraceWizard Demo Version screenshot

The parameters of each water using event are stored within the expert system computer program and assigned the corresponding end use type. For impossible or difficult to distinguish events, a trained analyst can use the graphical user interface to train the program to identify the right end use. Some effort is required during the analysis, but the set-up time and the amount of required hardware is reduced. Due to the nature of the method, it is not necessary to enter the residence in most cases, which reduces the data bias. According to the manufacturer, the analysis of a two week flow trace, which has more than 120,000 records, can be completed in about one hour (DeOreo and Mayer 2000).

For simplifying the analysis it is suggested in the Tampa case study that a signature trace of each fixture should be captured by the logger. This is achieved by operating each fixture in the home, and noting down the time of operation. Each fixture should be operated separately for a 1 to 3 minute interval. Thirty seconds should be allowed between the operation of each event to allow for clear and discreet water use events. This step can be included in the site visit, when installing the logger, or conducting the survey. The more accurate the flow information available, the easier it is to obtain accurate disaggregation of water use events (DeOreo et al 2004a). The analysis was further simplified by the audit, which provided useful information on the water use. A paper by William DeOro et al suggests that if time and money is not an issue, home visits coupled with data logging will provide the most accurate determination of residential water use patterns (DeOreo and Mayer 2004b).

The **advantages** of this system are:

- just one metering system for each house which is easily installed
- no further plumbing required if an existing water meter is in place
- non-bias information since people won’t even know they are being monitored
- no need to enter the house.

The **disadvantages** are:

- expensive equipment (meters, loggers and software – NZ$1,000–4,000)
- never been tested in a low pressure system (houses with less than 8 m of head i.e. header tank or pressure-reducing valve).

The software package retails at a price of US$1,495. Since this software can be used on numerous occasions it would be wise purchasing a full copy. The demo version, which is freely available, showed that the main part of the numerical end use analysis can be done by using this tool.

4.2 Metering of each end use

Another option to capture the end uses is to install water meters at every end use appliance, and log the output of each meter using either separate data loggers or one central data logging system. The advantages of this arrangement are that the analysis of the data is straightforward since each end use is monitored separately. The disadvantages are:

- very intrusive method and only recommended when a new building is constructed
- not suitable for a large sample size
- extensive plumbing is required
- not suitable for low pressure systems since a pressure reduction at the various end uses occurs due to the large pressure drops of the commercial meters
- large number of meters required for each house.

The disadvantages and likely problems with this arrangement outnumber the advantages. Due to the high number of installations required, extensive plumbing is needed which increases the risk of leaks. There was no study available which used this method for monitoring multiple households.

4.3 Water usage diaries

With this method each person is given a diary to record what amount of water they are using and what type of end use (e.g. write down when a toilet is flushed or how long they have showered). Research with this technique has shown that people greatly underestimate their use (Cordell 2002). Due to the intrusiveness of the data collection method a change in water using habits can occur, which is not desirable when wanting to know the actual consumption. Also participation levels can decrease due to the great deal of self-involvement, which reduces the reliability and the accuracy of reporting.

5. EQUIPMENT FOR MEASURING FLOWS

A large databank of equipment information has been drawn together to look at the different types of flow meters and data logging equipment. Suppliers have been contacted worldwide with the aim of finding suitable equipment for monitoring the water end uses in New Zealand. These suppliers include: BadgerMeter, Aquacraft, GMI, Unidata, NIWA, Monatec, Prosol, Eurotec, Liquipsales, PKP Instruments, Clarksol, ManuFlo, WaiTEK and others.

5.1 Water meters

Most water meters cause a pressure drop when installed in the feed line after the storage tanks. This is not desirable since the pressure reduction can be physically felt when using certain appliances, especially in a low pressure system (e.g. the shower). Flow meters are available that do not cause a pressure drop, for example, the magnetic inductive flow meter which uses Faraday’s law of induction. These meters have high costs associated with them, and are not suitable for a large-scale study. The

German manufactured meter retails at a price of US$1,200 per unit. This meter also requires a power supply, which adds to the cost and complexity of monitoring. The same applies when using an ultrasonic flow meter, which costs several thousand dollars per unit.

Other meters like the turbine or paddle wheel meter have a low pressure drop and slightly lower costs than the electromagnetic meter. However, Peter Mayer from Aquacraft suggested that the resolution in the low flow rates is not adequate for disaggregation purposes and should not be used in metering the end uses. We had a look at three different turbine flow meters from GPI, in the range of NZ$250 to NZ$920, plus the cost of an output unit at NZ$330. The flow meter which suited our requirements was the NZ$920 model, which comes to a total cost of NZ$1,250, including the output unit. Another factor was that at each end of the flow meter a straight section of pipe at 10 times the pipe diameter was needed in order to eliminate any turbulences; this would have added further complications and costs to the project. The ½ inch model, with a flow rate of 5–45 litres per minute (LPM) had a very high pulse output (k-factor) of 2,500 pulses per litre. This high frequency signal would have been problematic to pick up via a data logger and would have reduced its memory significantly. Figure 6 shows a diagram of the turbine flow meter.

Figure 6: Turbine flow meter (Source: Great Plain Industries Inc, USA)

The requirements for our flow meter are:

- flows range should be between 3 and 80 litres per minute
- low pressure drop (no pressure drop desirable)
- resolution of more than 20 pulses per litre
- output for logging pulses (e.g. reed switch).

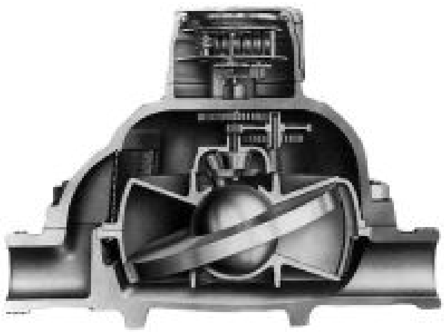


Figure 7: Nutating disk meter (Source: AMS Instrumentation & Calibration Pty Ltd)

Figure 8: Kent PSM meter

A nutating disc meter as shown in Figure 7 would be suitable for the data collection, as long as the pressure drop is not too large. The meter which is produced by BadgerMeter Inc in Milwaukee WI works on the principle of continuously filling and discharging the measuring chamber. As the chamber is set into motion, a magnet rotates whose signal is picked up by an additional magnet or electronic sensor through the wall of the meter. Each rotation is equivalent to a fixed volume. The cost of one water meter and output unit, which is necessary to pick up the signal, is NZ$245 and NZ$315 respectively. The unscaled transmitter provides an output of 52.42 pulses per litre for the 5/8 inch model. This is more than enough for using this flow meter to obtain data for disaggregation purposes.

We have also experimented with a standard Kent water meter shown in Figure 8 for NZ$84. This meter gave us a large pressure drop, and the meter's resolution did not meet the requirements since the output gave only one pulse per litre which is too low to produce data for disaggregation purposes. We tried to increase the resolution by a factor of 10 by modifying the mechanism within the meter, but as the dials spun around 10 times as fast, it caused malfunction within the meter's mechanism. It was decided to drop the idea and invest our resources in finding alternative flow meters.

Once a decision is made on the type of flow meter, it can then be decided how to log the pulse outputs with a data logger.

5.2 Data logging

After we have decided on the type of water meter we are going to use, we have to decide on the type of logging system. At this point we can not identify which logger will be used. There are many different types of loggers and logging systems available. The main criterion for the logger is that it is capable of logging at a 10 second interval. This means that every 10 seconds the number of pulses given off by the flow meter in this interval are stored in the logger's memory. A 10 second recording interval has been proven to be most successful when it comes to balancing the accuracy and the storage capacity of the logger (DeOreo and Mayer 2004b). Most studies that use the disaggregation method use this recording interval.

The logger should have an adequate memory to reduce the number of times it needs to be downloaded. A download interval of two or more weeks would be desirable. The greater this interval becomes the more money can be saved, especially if the project duration is over a one year period or longer. Loggers with an incorporated mobile phone chip are available which are capable of transmitting the data to any computer connected to the phone line. The higher costs of these loggers can be compensated for by eliminating the time spent for manual downloading the data in the field. A wide range of logging systems are available with a wide price range.

The logger used in the American Water Works Association case study, the MM 100El by Brainard & Co, has a retail price of US$2,490 per unit. These loggers can be supplied for US$2,000, but this is still too expensive when considering the available budget. The costs would be reduced by working with local equipment.

Figure 9: Modified BRANZ logger

The actual amount of time needed for capturing the data from each logger also needs to be kept to a minimum. Some loggers with a full storage take 20 minutes to download completely. This additional time does not only consume resources and cost additional money, but might also put stress on the inhabitants by consuming their time as well.

We also worked on a modification of the existing BRANZ loggers, which is shown in Figure 9. The reed switch, which picks up the signal from a water meter, is shown in the top half of the picture. At present our loggers were only capable of picking up pulses at 1 minute intervals. After modification, pulses at a 10 second interval could be recorded. This was successfully tested by logging the pulse output of a Kent water meter, which was attached to our caretaker's house. A large sum would have to be invested in order to modify our loggers even further. The memory size of the logger would have to be increased, which increases the present download time of 20 minutes for a logger whose memory is filled. Major improvements would have to be made to the logger for it to be used for capturing data for disaggregation purposes. For the pilot study it is not feasible to carry out these major changes, but for a large-scale study it would be worthwhile thinking about this option. If the development costs can be balanced against the cost of purchasing a certain number of loggers which are available, then it can be said which option is more practical or economical.

5.3 Summary

The flow trace analysis methodology is a useful tool for monitoring a large number of samples. It is the least intrusive method when wanting to capture data scientifically. More and more institutes worldwide make use of the principle which has a great potential for the future. In our opinion, if we are wanting to monitor the end uses, there is no way around it.

At this point the nutating disk meter provides us with the best alternative to balance cost against loss of pressure, which is one of the biggest problems that concerns our monitoring. The output has a more than adequate resolution, which should be unproblematic to be picked up by a logger. The cost for one meter would be about NZ$560. A decision on the type of logging system can not be made at this stage of the project. Many different systems in different price ranges (NZ$100–3,500) have been looked at, and once we can be sure our flow meter is operating in the way we require, a decision on the logging can be made.

6. FACTORS AFFECTING USE

There are many factors that influence the use of water including demographics, climate, available technology (i.e. low flush toilets), seasonal and daily variations. This section addresses some of the factors involved which have to be accounted for in our study. At the end of our study, we hope to identify which factors have a major impact on water consumption in New Zealand.

6.1 Demographics

Demographic trends are the biggest influencing factors affecting the residential use of water (Griffin and Morgan 2005). If people's behaviour and perceptions of water use can not be influenced towards sustainability, then there is little that can be done to improve the current situation. Even the implementation of using water-efficient fixtures has to be introduced by changing public behaviour. Toilets are more affected by the technological issues, since continuous improvement is made in reducing the flush volume. The behaviour of using the toilet can not be changed, but the volume of water which is used with each flush can. Today, toilets are available with a flush volume of 6 litres per flush (lpf), but a lot of toilets have a flush volume much greater than that.

The 6 litre flush toilet was made mandatory in the United States under the US Energy Act 1992 which came into operation in 1995. At the same time, 23 litre toilets were allowed in Manitoba, Canada (Griffin and Morgan 2005). These variations make it hard to compare the end uses in different countries. As observations have shown, there are still New Zealand homes which have toilets with a flush volume much greater than 23 litres. When carrying out a large-scale study this factor can be explored in further depth.

The behavioural issues affecting the use of water are outlined in the following Table 5. These are general tendencies, and do not necessarily apply to each household. The report A *New Water Projection Model Accounts For Water Efficienc*y (Griffin and Morgan 2005) by the Canadian Mortgage and Housing Corporation explores these demographic factors and their effect on water consumption.

Table 5: Factors affecting the use of water

Factors	Description
Household (Griffin and Morgan 2005)	The bigger the household, the bigger the overall water consumption, but the smaller the per capita consumption.
Age of occupants (Griffin and Morgan 2005)	Elderly people tend to use less water. Water usage depends on the year you were born. People are not likely to change their behaviour during their lifetime (birth date model).
Household income (Loh 2003)	The higher the income the greater the use of water. This is dependent on a series of factors.
Garden size	The greater the garden size (area of irrigated land), the higher the overall consumption since more land requires more irrigation.
Number of teens (AWWA 1997)	The presence of teens tends to increase the water use.
Number of full-time working adults (AWWA 1997)	People who work full-time use less water around the home. They use the water somewhere else (e.g. office), so the overall consumption within their household is smaller.
Watering behaviour	If your garden gets watered twice a week, you use more water than someone who just waters once a week.
Rainfall and climate data	The higher the amount of rainfall, and the lower the temperatures, the less water is being used for irrigation which is a major end use.

There are other social and demographic factors that need to be explored. At the end of the study we hope to identify these factors and see what other trends occur in New Zealand. At this point we do not have answers if the factors in the table apply to New Zealand households in the way they applied to other nations. By using a specially designed questionnaire, which includes questions from the HEEP survey (Isaacs et al 2004), we hope to address these factors and learn more about the behavioural issues. After the analysis of the questionaries we can give more definite answers to these questions.

6.2 Seasonal and daily variations

The DWUS study (Loh 2003) conducted in Perth shows the monthly variation of water use. Since monitoring was undertaken for a period of 20 months, enough data was available. Data shows that the seasonal variations are mainly due to outdoor uses. During the winter months the average usage dropped to less than 100 l/p/d, whereas in summer more than 1,800 l/p/d were used by high income houses and 1000 l/p/d by low income houses. High income houses tend to use more water outside than low income houses. The justification was that this could be due to the ownership of automatic reticulation watering systems, which are more likely to be present in high rather than low income houses. Auto reticulation systems use nearly twice as much water as non-reticulation systems as identified in the study (Loh 2003).

Numerous reports have shown that the hourly consumption rates vary during the day. The following graph (Figure 10) taken from the Yarra Valley Water report shows this variation in two different seasons of the year.

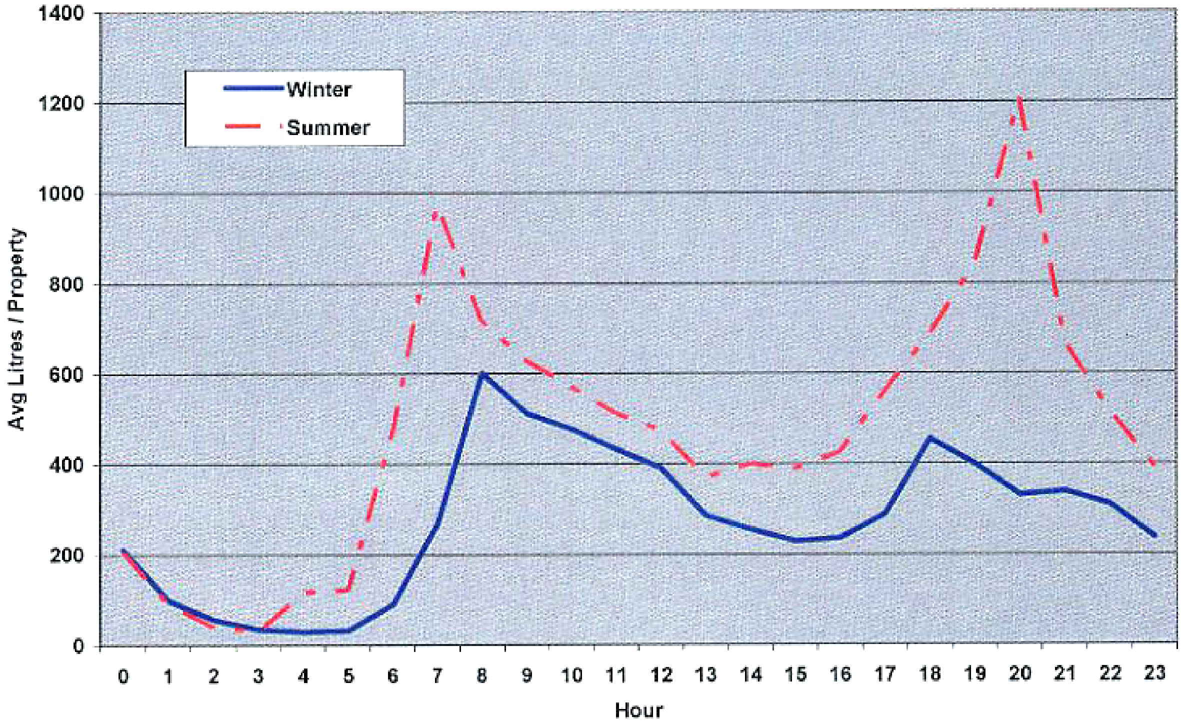


Figure 10: **Average hourly profile (Source: Yarra Valley Water report – Roberts 2005)**

The graph shows two peaks occurring at around 8 am and 6 pm in the winter, and both seem to arise through shower use. In the summer months these peaks are shifted to around 6.30 am and 8 pm. The peak in the morning is the result of shower use and the evening peak is dominated by irrigation (Roberts 2005). The flow trace analysis helped to determine the major factors that were causing the peaks. Since we can identify at what time each appliance is used, it is easier for an analyst to see daily and seasonal trends. The peaks are identified for each of the end uses. The DWUS study suggests similar patterns.

When looking at similar projects, I suggest to monitor two separate periods of the year, summer and winter, to see the variations between the seasons since garden-related use is a major factor during the summer. Two to three months for each season should be adequate to collect the necessary data for end use analysis. During the two periods, while the equipment is still in place, the water consumption should be recorded at 5 to 10 minute intervals to obtain additional information. The recording interval for this time of the year between the periods is still debatable, and depends on the capacity of the loggers and download times.

I do not think it is necessary to collect end use data for a whole year, since this would significantly add to the costs. Analysing data into end uses is very expensive as large amounts of data have to be processed and analysed.

7. WATER PRESSURE

As in New Zealand, there are many different types of water distribution systems in the residential sector. According to the Year 9 HEEP report (Isaacs 2005), 72% of New Zealand houses have a low pressure hot water system. This system is based around a header tank, and more recently around a pressure-reducing valve, feeding an open vent cylinder (less than 3.7 m or 37 kPa). Over recent years the trend has been towards medium pressure using a pressure-reducing valve (7.6 m or 75 kPa), and more recently to mains pressure hot water systems (Isaacs 2005).

For houses that have a mains pressure hot water system, the data collection method when using the disaggregation process is simplified. However for low pressure systems, it makes it hard to measure the flows using standard equipment due to the pressure drops involved. This can be a problem, especially in the shower. Another point is that the flow trace analysis method has never been tried in a low pressure system. Section 5.1 addresses the problem, and talks about measures that can be taken to overcome the problems associated with the low pressures.

We would need to use a water meter with a minimum or no pressure drop. The magnetic inductive meter (US$1,200) and an ultrasonic meter (a few thousand dollars) would produce no pressure drop, but due to the high costs involved it is not feasible at this stage. The nutating disk meter would be a good alternative due to a relatively small pressure drop in the low flow rates. This will be tested in the lab before installation in a pilot study house. The cost of this meter (currently NZ$560 for one set-up) would make it practicable to be used in a large-scale study, especially if multiple meters are required in the homes due to the variations in plumbing installations. It is very important to use a flow meter that meets our requirements, since the data is only as accurate as the flow meter.

According to Peter Mayer, flow trace analysis has never been tried in a low pressure system. The flows will be much lower and much more similar for all events. Hence, it might not be easy to identify between events in this sort of system. If we do not try to implement this technique, we will never know if this is the case.

8. WATER CONSUMPTION

The following section shows an overview of the identified water usages in various parts of New Zealand. In most cases the total water consumption is divided by the population. It is not always distinguished between residential, commercial, industrial or agricultural use. The values are summarised in Table 6.

Table 6: New Zealand water consumption rates

Area	Consumption l/c/d	Source
Hutt City	381	Wellington Council – Annual Report 2005 (see References)
Porirua City	327	Wellington Council – Annual Report 2005
Upper Hutt City	408	Wellington Council – Annual Report 2005
Wellington City	451	Wellington Council – Annual Report 2005
Paekakariki*	603	Kapiti Coast Council (see References)
Paraparaumu/Raumati*	621	Kapiti Coast Council
Waikanae*	808	Kapiti Coast Council
Otaki*	1070	Kapiti Coast Council
Kapiti average	1300	Dominion Post 3/12/2005 (see References)
Auckland	185	Auckland Water Management Plan 2004 (Dziegielewski 2000)
Wellington	240	Auckland Water Management Plan 2004
Invercargill	245	Auckland Water Management Plan 2004
Hamilton	260	Auckland Water Management Plan 2004
Palmerston North	265	Auckland Water Management Plan 2004
Christchurch	280	Auckland Water Management Plan 2004

*Peak consumption summer 2001

A large amount of water is used by residents of the Kapiti Coast. According to the 3 December 2005 *Dominion Post* article 'Kapiti is Parched – Despite a New $13m Borefield, They Still Can't Turn on Their Sprinklers', 1,300 litres of water per person are used each day when 200 litres per person is ample for household washing and cooking. Most water is used for lawns and gardens, where it quickly drains into the sandy soil. The council hopes to reduce the consumption to 400 l/p/d by its conservation strategy. Due to a population increase of 1,000 people per year, additional pressure is put on water resources.

Table 7 shows a summary of water consumptions in different parts of the world, taken from a research paper (Dziegielewski 2000).

Table 7: Observed variability of residential water use (Source: Dziegielewski 2000)

Sample population of water users	Observed residential usage litres/capita/day			Source
	minimum	maximum	average	
Average domestic withdrawals in 80 countries	6	540	116	WRI 1999
Domestic supply in 50 States of the United States	132	806	382	Solley et al 1998
Several hundred places in developing nations	11	930	N/A	Dietrich and Henderson 1963
Various urban areas in 15 countries	13	675	218	White et al 1972
Individual 330 households with piped water in East Africa	11	660	139	White et al 1972

From the table it can be seen that there is a wide range of water usage throughout different parts of the world. However, the validity of the source can be questioned, since throughout this research we came across higher maximum consumption rates. In the Yarra Valley Water study (Roberts 2005) some individual users were consuming a couple of thousand litres per capita per day.

Unless residential areas are not metered, it is impossible to obtain figures for residential consumption. In most cases, the per capita water consumption is measured by dividing the total water usage by the total population. This, however, does not indicate where the water is being used.

9. CONCLUSION AND RECOMMENDATIONS

By adopting and modifying the data collection methods used in other parts of the world a custom design can be used to measure both the water end uses in low and high pressure systems. It is likely that some monitored homes will require custom installations, due to the nature of the plumbing. Once our pilot study gives useful results, the methodology can be used in a large-scale study which extends nationwide.

By looking at the various options, we recommend to use a non-intrusive data collection method like the flow trace analysis, since a large number of houses can be monitored without introducing data bias. End use monitoring should be carried out over a summer and a winter period for two to three months to capture the seasonal variations. During this period, 5 to 10 minute data should be recorded while the equipment is still in place to capture additional data for analysis purposes. The analysis of raw data for disaggregating into end uses is a very expensive process. It might be more valuable to monitor a larger number of homes for a shorter period of time. I also recommend to use a 10 second recording interval for the main study, since this has proven to be the best balance between accuracy and the capacity of the loggers. A five second logging interval could be tested in a sample house for a few days to see what the variations are and whether the accuracy in disaggregation is improved.

When we have gathered the know-how after the pilot study, a larger sample of homes should be monitored to obtain an increased data set. Flow trace analysis is also a method which has a great potential for the future, and knowledge gained by us on this topic can be a benefit to many parties throughout New Zealand. By developing a working methodology, the question about where water is used in homes should be understood in more detail and incentives to use water more efficiently can be implemented or improved.

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