Study Report

SR469 [2022]

Residential water use in New Zealand

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water NEW ZEALAND
The New Zealand Water & Wastes Association Waiora Aotearoa

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Preface

In 2007, BRANZ completed the Water End-use and Efficiency Project (WEEP), which looked to collect water-use data from 12 households in Kapiti (Heinrich, 2007). The following year, the experimental approach was repeated for Watercare for 51 houses in the Auckland Water Use Study (AWUS) (Roberti, 2010).

This project looked to build on these studies to collect new residential water-use data from around the country using current data collection methodologies.

A separate BRANZ study report investigating residential water tariffs in New Zealand (Garnett & Sirikhanchai, 2018) was also completed as part of this overall project.

Acknowledgements

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A number of past BRANZ staff and contractors have worked on this project, which would not have been possible without their input – Lee Bint, Amber Garnett, Sandi Sirikhanchai, Riaan Labuschagne, Andrea Simpson, Nick Brunsdon and Anne Duncan.

Nic Guerrero, who is a current research assistant at BRANZ, helped with additional survey entry towards the end of the project.

Thanks to Lesley Smith from Water New Zealand who has been a stalwart supporter of this project.

Thanks to Colin Whittaker, Teresa Scott and Kobus van Zyl from the Department of Civil and Environmental Engineering, Faculty of Engineering at the University of Auckland who took on the difficult task of end-use identification, which they have reported on in a separate report.

These councils and water supply authorities participated within this project to varying degrees: Carterton District Council, Central Otago District Council, Far North District Council, Gisborne District Council, Gore District Council, Horowhenua District Council, Kawerau District Council, Marlborough District Council, Masterton District Council, Matamata-Piako District Council, New Plymouth District Council, Palmerston North City Council, Selwyn District Council, South Taranaki District Council, South Waikato District Council, South Wairarapa District Council, Southland District Council, Stratford District Council, Tararua District Council, Tauranga City Council, Timaru District Council, Veolia, Waimakariri District Council, Waipa District Council, Watercare, Wellington Water, Western Bay of Plenty District Council, Whanganui District Council and Whangarei District Council.

Finally, special thanks to all of the participating homeowners who completed surveys and allowed us to install water meters at their homes.

Residential water use in New Zealand

BRANZ Study Report SR469

Author

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Reference

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Abstract

There is limited information available on how water is used in New Zealand homes. Previous BRANZ work has been restricted to small numbers of households in particular geographical areas. This study invited participation from councils and water supply authorities from around the country, and a widespread 66-household sample was obtained.

The data collected for each household was the total water use collected at 10-second intervals, which was complemented with an occupant survey and a detailed inventory of water-using appliances and fittings from within the home.

With the water data being collected at a high rate, there is the potential that machine-learning techniques could be used to estimate which water appliances and fittings were being used within the home. Colin Whittaker, Teresa Scott and Kobus van Zyl from the Department of Civil and Environmental Engineering at the University of Auckland have been investigating this possibility and have reported on this in a separate report.

The median water use for the sample was 159 litres per person per day for winter and 231 litres per person per day for summer. The average water use over the winter and summer periods was 34% and 26% respectively higher than the median water use due to a number of households with high water use having an undue influence on the average value.

Keywords

Residential water use, water efficiency, WELS, water end-use.

Contents

Figures

Tables

Executive summary

This project looks to update residential water-use information with a nationwide measurement of water use from households from around the country. Participation was invited from all councils and water supply authorities. However, a number of regions with larger populations chose not to participate while regions with smaller populations were more likely to be included. A map of those participating is shown in Figure 1. The regions with smaller populations also tended to have poorer cellular coverage, and with other data collection issues (see Appendix B), the overall sample size was smaller than originally planned with measurements completed from 66 households.

The **average** water use observed was:

- 213 litres per person per day for winter
- 292 litres per person per day for summer.

The distribution of daily water use is skewed with many households with higher water use. A 'typical' household is more likely to be better represented by the median (middle value when the values are ordered) than the average.

The **median** water use observed was:

- 159 litres per person per day for winter
- 231 litres per person per day for summer.

The median water use should be more routinely reported than the average water use.

The dataset includes measurements of water use at 10 second intervals and small water flows. This high-resolution data allows post processing to be completed on the data such as estimating the water end-uses present with the data (see Appendix A).

This end-use disaggregation was not able to be completed within this project but the data has been passed on to Colin Whittaker, Teresa Scott and Kobus van Zyl from the Department of Civil and Environmental Engineering, Faculty of Engineering at the University of Auckland to investigate the potential to determine the end-uses from advanced data processing.

A survey was completed by each household, which provided a range of information on the occupants, their water-using appliances/fittings and how these appliances/fittings are used.

Many respondents were not aware of the Water Efficiency Labelling Scheme (WELS) star rating of their appliances/fittings. The appliance with the highest proportion of star ratings known was the washing machine with 18% of homeowners aware of the star rating.

The washing machine is an appliance type that has changed considerably since the AWUS study (Roberti, 2010) where less than 6% of households had a front-loading washing machine. This project has seen the ownership of front-loading washing machines increase to 36%. As front-loading washing machines can have much lower water consumption than top-loading washing machines, this could represent a good water savings potential.

Less than 10% of the households had a rain tank of any size, so there remains a large potential to increase the number of rain tanks present.

The amount of water used for outdoor irrigation can be large. Around 28% of homes had a sprinkler system with these roughly split between automatic and manual systems.

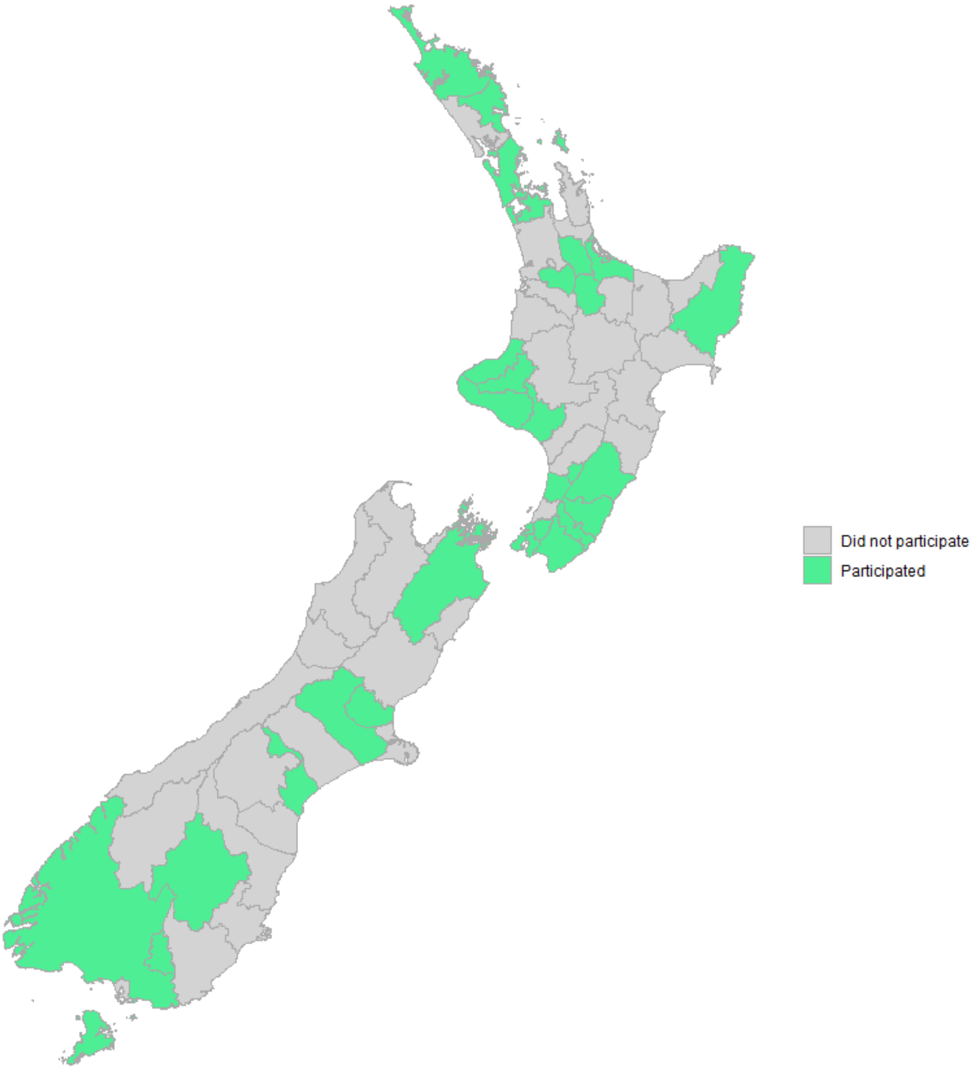


Figure 1. Map of the council and water supply authorities participating in this study.

1. Introduction

Freshwater is plentiful in New Zealand by international standards. A water management road map from NZIER (Kaye-Blake, Schilling, Nixon & Destremau, 2014) reported that New Zealand has the fourth-highest per capita water availability among OECD countries after Canada, Iceland and Norway. This is believed to be due to New Zealand's small population and the abundance of national water resources. However, it has also been stated that "New Zealand is fast discovering that freshwater is not an unlimited resource … most regions have at least one river (surface water) or aquifer (groundwater) that is either fully or over allocated, or likely to become so" (New Zealand Business Council for Sustainable Development, 2008, pp 3–4).

Demand for freshwater is increasing for a variety of reasons. Other than hydroelectric generation, irrigation is the main consumptive use of freshwater (Booker & Henderson, 2019). It has been subject to strong growth in part due to a change of pastoral farm that has seen a 69% increase in dairy cattle from 1994 to 2015 while seeing a 41% decrease in sheep numbers (Ministry for the Environment, 2017). The total national irrigated land has increased by around 70% between 2002 and 2017 with the total irrigated land in Canterbury and Otago comprising close to 80% of total national consents (Ministry for the Environment, 2017).

1.1 Background to residential water use

Residential water use is supplied by both council and council-controlled organisations. Currently, central and local government are involved in an extensive three waters consultation process,[1] which will review how drinking water, wastewater and stormwater are supplied throughout the country.

Water New Zealand undertakes the National Performance Review annually, which reports on drinking water, wastewater and stormwater services provided by the various council or council-controlled organisations. The 2019–2020 National Performance Review (Water New Zealand, 2020) indicated that water use had increased over the proceeding 5 years and that a total of 5.6×10^8 m^3 of water was supplied in 2019/20.

Pressures on residential water use are likely due in part to an increase of overall population. New Zealand's population grew 17% from 1996 to 2012, driving a 10% increase in urban land area (Ministry for the Environment, 2017).

This report does not focus on a supply-side response to these pressures but instead looks at quantifying water use for residential users. Measuring water use at an individual household level may assist with understanding some of the issues for residential water demand management, which is briefly discussed in the remainder of this section.

1.2 Opportunities for better management

The New Zealand Water Efficiency Labelling Scheme (WELS) was updated in 2017 (Ministry for the Environment, 2019) and looks to provide water efficiency information to consumers at the point of sale for washing machines, dishwashers, toilets and urinals, showers and taps.

[1] www.dia.govt.nz/three-waters-review

This information is presented in the form of a label (Figure 2) that is similar to the energy rating labels used for electrical appliances. This label is either affixed to the appliance or attached as a double-sided label. This labelling scheme is closely aligned to the scheme that runs in Australia.

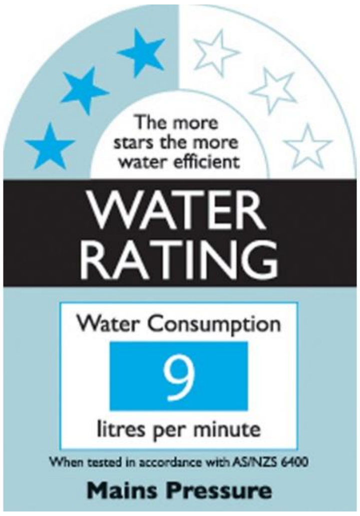


Figure 2. Example of a WELS label.

The building industry has a key role in enabling good water demand management. Plumbers install and often specify or recommend the major water-using devices in the home such as the toilets, showers and tap fixtures (Conder, 2008) and therefore have the potential to set the overall water efficiency of the home. These choices are subject to a number of trade-offs (most notably cost) so making them visible would be beneficial. Some examples of increasing the visibility of the water efficiency choices may be to leave the WELS labels on toilets, washing machines and dishwashers in a new home. This would make the new homeowners aware of the level of water efficiency of these items. Another way would be to undertake an environmental rating scheme such as Homestar[2] to recognise the water efficiency features of the home.

In addition to water efficiency, reducing the water drawn from the water service provider can also be achieved by the householder using rainwater harvesting or by maximising the use of water via greywater recycling (Conder, 2008).

The New Zealand Building Code does not provide any information on what good performance is and only sets a minimum performance level (James, Saville-Smith, Saville-Smith & Isaacs, 2018). Having information available on the water efficiency of the building would be beneficial as well as programmes to encourage higher levels of water efficiency.[3] Previous attempts to limit hot water use (primarily motivated by energy efficiency) were abandoned when the public was not supportive of the added regulation (Pollard, 2010).

Water metering and volumetric charging are common water demand management techniques. Water metering is now present in more than half of all New Zealand homes (Water New Zealand, 2020), and a variety of pricing mechanisms are in place (Garnett & Sirikhanchai, 2018). The beneficial experiences of implementing water metering and volumetric charging for a number of councils have been documented frequently (Water

[2] www.nzgbc.org.nz/Homestar
[3] www.branz.co.nz/sustainable-building/up-spec/water-management/

New Zealand, n.d.; Lawton, Birchfield & Wilson, 2008; Stewart, 2009; Controller and Auditor-General, 2018). Once water meters are in place, greater levels of water management are possible. This can be from external parties that could compare water use between households, which could allow for the use of social norms to encourage water conservation (Schultz et al., 2016). The water-use information could also be used by the occupant to help them understand their own usage and potentially help them identify leaks.

Collected data from water meters at sub-hourly intervals using data loggers or as part of an integrated smart meter allows for a much-enriched analysis of water use to take place (Cominola, Giuliani, Castelletti & Rizzoli, 2015). This could include examining the overnight usage for signs of leaks, the comparison of usage during weekdays and weekends and, where the data collection is sufficiently resolved, data on individual water-using events leading to identifying the end-uses present within the home (see Appendix A).

Currently, knowledge on how water is being used in New Zealand homes is limited. There have been few data collection projects and only limited numbers of households included in such studies. As data collection technologies improve, there will be increasing opportunity to collect more-accurate water data from more households and to improve the overall understanding of residential water use.

2. Previous studies

2.1 New Zealand household water-use studies

In the mid-2000s as BRANZ was completing its first detailed study of energy use in New Zealand homes (Isaacs et al., 2010), there was interest in undertaking similar studies with a focus on water use in homes.

In 2005, Beacon Pathway was planning the NOW Home, a demonstration home that would include many sustainability features (Bayne, Jaques, Lane, Lietz & Allison, 2005). The home was designed with water-efficient appliances and low-flow fittings and also included a 13,500 litre rainwater tank, which was integrated into the household plumbing. This home would be occupied by a regular family and would be instrumented to measure the water-use characteristics of the home.

The initial intention for the measurements was to record the total water use drawn from the council supply as well as the water supplied from the rain tank. As the house was under construction, the ability to place additional water meters into each water line was reasonably straightforward, enabling the recording of all the water end-uses individually. These meters were generally within the roofspace of the NOW Home. The meters were wired back to a data-acquisition system, which recorded the 24 water uses at 1-minute intervals.

The results of the NOW Home are published in several reports by Beacon Pathway (French, Heinrich, Jaques, Kane & Pollard, 2007; Pollard, French, Heinrich, Jaques & Zhao, 2008).

Currently, Watercare is working with Fletcher Living to develop a pilot water efficient home called the 1.5-degree home.[4] This pilot will look to achieve MBIE's water-use target of 75 litres/person/day (Ministry of Business, Innovation & Employment, 2020) using a variety of monitoring and water-saving technologies.

2.1.1 WEEP – Kāpiti Coast

While data from a single home can be instructive and provide interesting insights, the value of end-use data projects is magnified when multiple houses are included in the sample. The first multi-home study of water use conducted by BRANZ was the Water End-use and Efficiency Project (WEEP). This project studied 12 residential homes on the Kāpiti Coast (Heinrich, 2007).

The measurement approach used for the NOW Home was not suitable for use in WEEP. Placing water meters into existing water lines would be very time consuming, expensive and a major inconvenience for the homeowners.

A review of international approaches to water end-use studies (Heinrich, 2006) led him to look to instrument each home with a well-resolved water meter (34.2 pulses per litre) and to record the water use at a high time resolution (10 second intervals) during selected winter and summer periods. Specialised computer software (Trace Wizard)[5] is then used to pattern match characteristic appliance water-use shapes with the resulting overall water-use curve determining the end-use breakdown of the water use.

[4] https://www.linkedin.com/posts/watercare-services-limited_imagine-tracking-your-carbon-and-water-footprints-activity-6917660144969416704-7S90/
[5] https://aquacraft.com/data-downloads/trace-wizard/

The Trace Wizard program was able to resolve the total water use into a variety of end uses including indoor taps, showers, washing machines, toilets, dishwashers, bathtubs, outdoor irrigation and leaks. End-use classification is discussed further in Appendix A.

In the Kāpiti study, the maximum water use per person was higher in summer than the maximum use in winter, with on average an additional 35 L being used per person. However, indoor water use for summer was nearly identical with the winter indoor use, with the main difference being outside usage. During summer, outside usage accounted for 22% of the total water usage – three times the amount used during winter. The majority of outside usage was for irrigation. However one household out of the 12 surveyed was responsible for 57% of the total irrigation water use. Graphs for the distribution of the summer and winter water use are shown in Figure 3 and Figure 4 (Heinrich, 2006).

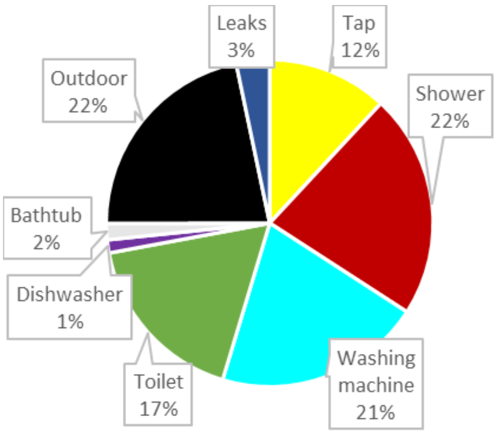


Figure 3. Summer water end-uses from Kāpiti.

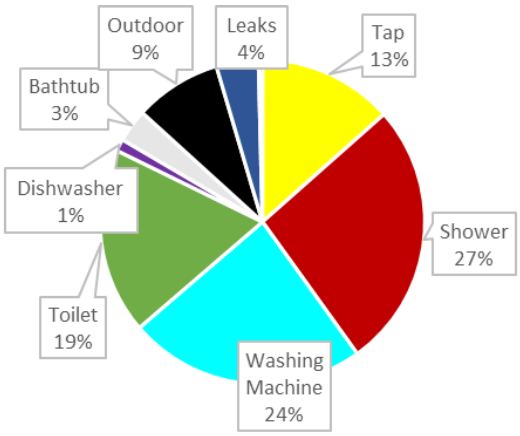


Figure 4. Winter water end-uses from Kāpiti.

2.1.2 AWUS – Auckland

Having obtained a small number of households in Kāpiti with end-use data in the WEEP project, various Auckland water agencies, including Watercare, sought to undertake a similar study with a larger sample based in Auckland. BRANZ was contracted to roll this out as the Auckland Water Use Study (AWUS) with a total of 51 households selected. Graphs for the distribution of the summer and winter water use are shown in Figure 5 and Figure 6. A detailed report was produced for Watercare and the six local network operators, and a summary and discussion of the study was given to the SB10 Conference in Wellington (Roberti, 2010).

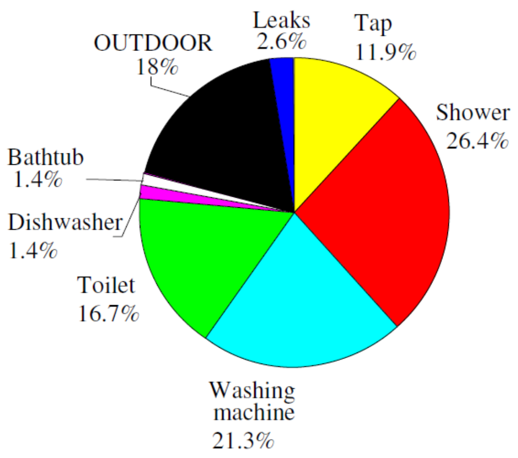


Figure 5. Summer water end-uses from Auckland.

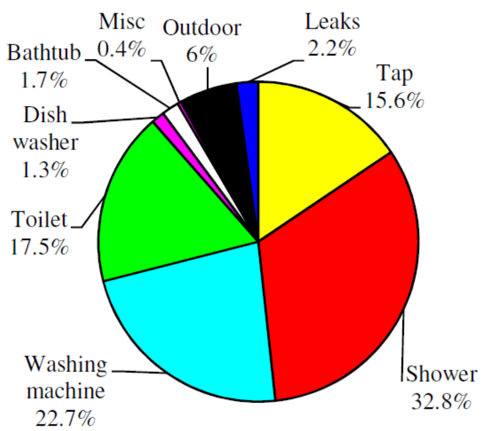


Figure 6. Winter water end-uses from Auckland.

3. Methodology

3.1 Objectives

From the previous studies of water use in New Zealand, a number of issues were identified.

Having measured water-use data alongside the characteristics of the home and occupants is key to informing how water is being used in the residential sector. While water supply authorities can readily install water meters and the associated data-collection equipment at the property boundary, additional information on the property (section size, size of garden, building footprint), the water-using appliances (numbers, types) and the occupants (number of household members, ages, income) enriches the data considerably but requires a specific data-collection process.

Currently, the number of households that have had water end-use monitoring has been small with limited national representation. End-use studies have only been undertaken in Kāpiti (Heinrich, 2007) and Auckland (Roberti, 2010).

Having water data recorded at multiple times per day for extended periods of time allows usage patterns to be examined such as the nature of overnight usage or the differences between weekday and weekend usage.

These studies have highlighted the importance of outdoor irrigation, but the measurement approach for both studies was to only take a snapshot view of water use in a summer period and a winter period. The understanding of outdoor irrigation would benefit from longer periods of monitoring where the duration of the watering session could be examined for a range of households.

The role and nature of non-useful water-use events (leaks) within homes is not well understood. These can take many forms – background low-volume events, progressively increasing events, which may take time to be noticed, or high-volume events following significant breakage of pipes, which may not be readily apparent.

3.2 Study approach

Collecting measurement data from houses is a long and expensive process. There is a persistent trade-off between the level of information collected about a single household and the number of households than can be included within the study. More information can always be collected from an individual household with more equipment, longer occupant surveys or detailed inspections from assessors, but this will limit how many households this could be applied to. Conversely, if a very large sample is used, only broad measures of water use and occupant characteristics can be considered and the findings will be more non-specific.

To deal with these scale issues, this project sought to have a multi-level approach. A large representative household survey would be matched to council metered water-use data. This large sample was not a focus for the project, and with the difficulty in obtaining consistent water-use data, this level of the project did not proceed. A smaller sample would use the survey information alongside daily metering that would be installed, and a targeted sample would use the survey information alongside high-resolution metering (recording changes of volumes of less than 30 mL) collected at very short intervals (10 seconds) to allow for end-use estimates to be made.

A large cost for measurement projects is the instrumentation and data collection associated with them. Often, a limiting factor for the reuse of the equipment is that various meters or sensors need to be installed by specialists (plumbers/electricians/gasfitters) and is generally time consuming.

This project was a departure for BRANZ in that it sought to partner with water supply authorities who would purchase appropriate metering and engage with a data provider who would supply water-use data from these meters that would then be shared with BRANZ. BRANZ would combine the data, provide feedback to the water supply authorities and provide a collective report.

Having the water supply authorities provide the metering was intended to share the costs of the project but would also provide the water supply authorities with equipment that they would be able to reuse or redeploy as they saw fit.

Unfortunately, this approach proved to be problematic and had major ramifications. This caused much effort to be redirected into equipment management and data cleaning. This resulted in major variations to the scope of the project. In order to provide more insights into water use, rather than detail what went wrong within the project, the narrative of project issues encountered is provided in Appendix B rather than within the main body of this report.

A detailed high-resolution sample of around 300 households was desired. The population proportions of each water supply authority were considered, and appropriate sample size breakdowns for each region determined, as shown in Table 1.

Table 1. Regional breakdown for the intended water-use sample (sample size), surveys returned (surveyed), houses instrumented with high-resolution meters (instrumented) and those that provided some reliable data (with data).

Region	Sample size	Surveyed	Instrumented	With data
Auckland	86	98	26	26
Canterbury	47	25	11	9
Wellington	39	71	6	4
Waikato	31	17	3	2
Bay of Plenty	21	42	12	10
Otago	15	4	2	2
Hawke’s Bay	11	0	0	0
Nelson/Tasman/Marlborough	10	8	0	0
Manawatu/Whanganui	9	29	7	7
Taranaki	8	23	11	2
Northland	7	16	7	4
Southland	6	2	1	0
Gisborne	3	6	0	0
West Coast	3	0	0	0
Overall	**296**	**341**	**86**	**66**

An additional 300 households were intended to be included in a companion sample that would use water data on a daily basis. The collection of daily data by the main data provider was not successful, and while some data was available from the other data providers, this level of the project was not investigated further.

3.3 Sample selection

The selection of houses was completed in conjunction with the local water supply authority. Information on the participation rates is not available as only successful participation details were collected.

Surveys were completed from households within a total of 29 of the 65 water supply authorities. A regional breakdown of this is shown in Table 1. Some of those surveyed intended to participate in the daily metering sample, thus the total number surveyed exceeds the desired sample size.

Where the selection only involved a few households, an ad hoc selection process may sometimes have been applied. For example, as new metering had to be installed at the site, households were sometimes selected from those properties for which pipes or metering were being replaced. Alternatively, some households may have come to the attention of the water supply authority for other reasons such as concern about their water use.

A survey form was sent to the household to self-complete and return. The survey covered a broad range of topics. It looked to identify how much water the household used and the water-using appliances (toilets, showerheads, baths, taps, washing machines, hot water systems and dishwashers) within the home, identifying some of their important characteristics. The survey also asked questions regarding the size of the property and the areas taken up by the house and garden as well as how the outdoor areas were irrigated. Basic demographic questions were asked for the occupants of the home as well as the ownership status and household income. The survey forms used are shown in Appendix C.

As the survey was self-completed, the quality of the replies varied. Many questions were not answered as intended, and many parts of questions were skipped over. The first question of the survey asked householders to estimate how much water they thought their household uses each day and how this estimate was made, and provided six lines for an answer. This could seem quite intimidating to a general respondent with the large amount of space suggesting that a thorough answer was required. For areas where water metering was undertaken, this was often completed with information from the rates/water invoice with little discussion. For areas where there was no water metering, the answers were more varied. Some made estimates that were quite unrealistic, and often the question was not answered. Previous surveys of attitudes to water use suggest that New Zealanders do not have a sense of how much overall water they use or which uses are important (Ministry for the Environment, 2009).

From the surveyed households, 86 households were instrumented for high-resolution water metering. Many of the remaining survey households instrumented for daily water metering did not participate further in the study (see Table 1 for a regional breakdown of these instrumented households).

A number of issues from the instrumented houses meant that data from only 66 houses was able to be used for this report. Again, a regional breakdown of these households is shown in Table 1.

While it was intended to have all of the houses with survey data complete the survey, a number of the households for which high-resolution water metering took place did not complete the occupant survey or could not be matched to a survey response.

Overall, 57 households completed both the survey and had high-resolution water metering undertaken on their homes (Figure 7).

As the study looks to relate water use to surveyed factors, the survey analysis for this report is restricted to the 57 households that also had water-use data available.

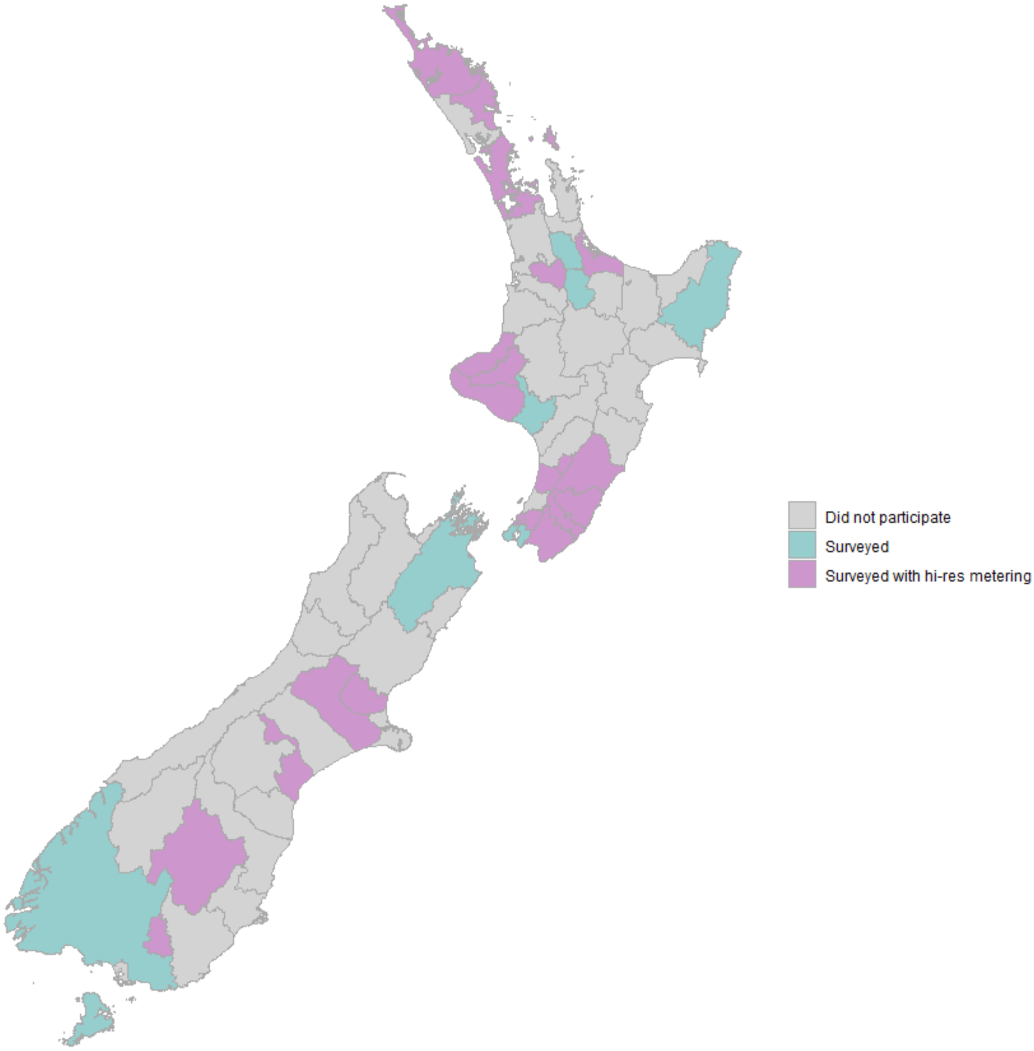


Figure 7. Map showing the council areas participating in this study. The purple areas show the councils that included the installation of high-resolution water metering while those in blue involved surveying only.

The data from the surveys was entered into Microsoft Excel using a flat structure. Responses for some questions that expressed a range for a value were imputed with the mid-point of the range to allow for quantitative analysis to be undertaken. For example, a range was often provided for the number of showers taken per week.

The responses for certain questions also included a variety of units even if a single unit was requested. For example, the section area was requested in square metres but was also given in hectares and acres. These other units were converted into the requested unit at the time of data entry.

The survey also revealed some inconsistencies. The hot water system section asked if the hot water system was mains pressure or low pressure. The next question was intended to identify what type of low-pressure system was present – a pressure-reducing valve or a header tank. Many surveys indicated that the house had mains pressure hot water but then also indicated a means of pressure reduction.

The responses for each question were examined across the sample and errors corrected where identified. For variables such as the section area that had a number of outlier values, the outliers were examined in detail, making reference to property valuation records to confirm the size of the property.

As is common with participatory surveys, the number of retired households was overly represented within the residential water-use sample. The sample also had an under-representation of those households who rented their home.

4. Results and discussion

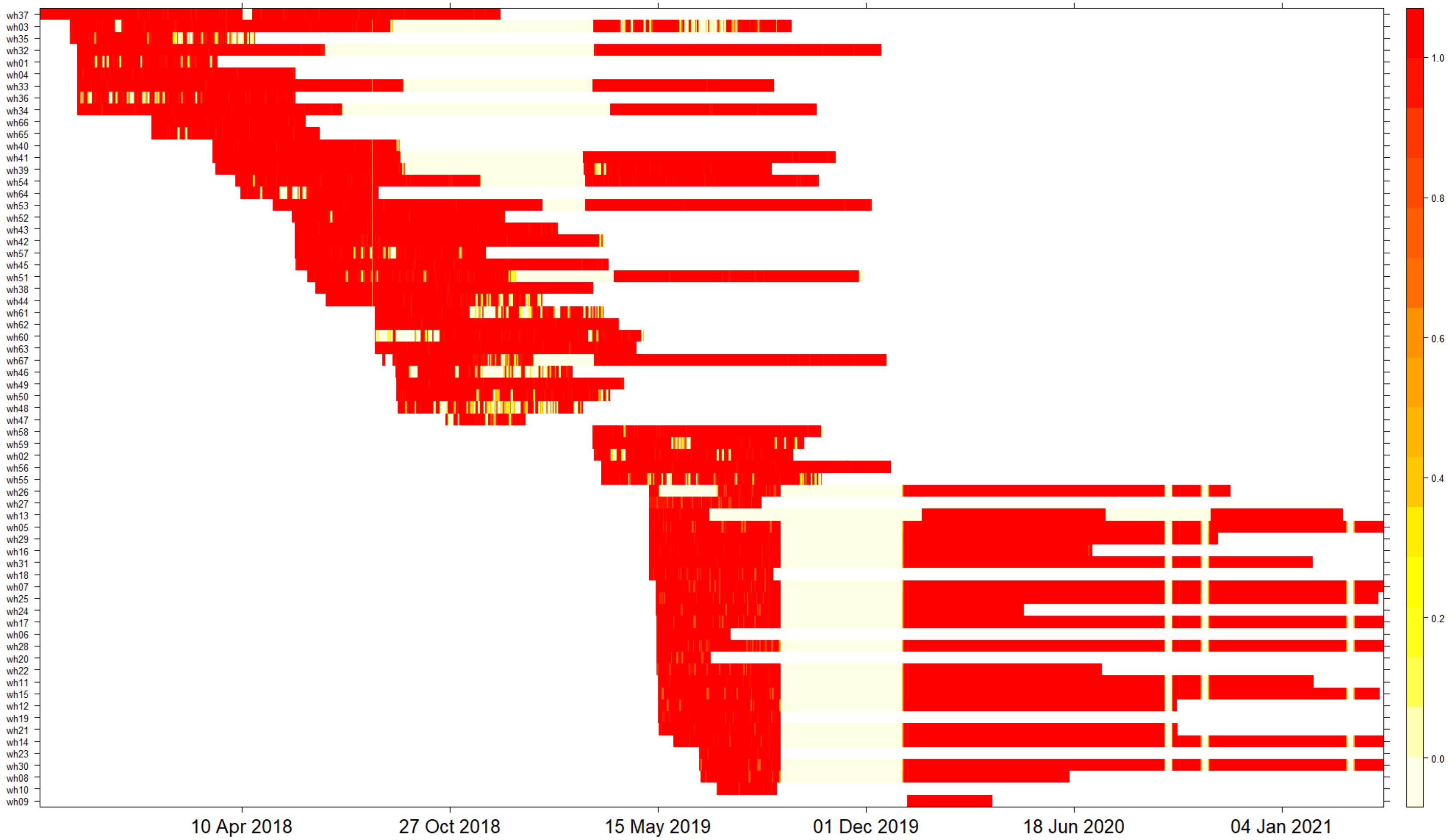
It was intended to collect 1 year of water meter data from each of the measured households. As was previously noted (see Appendix B), there were issues with the data collection, which has resulted in many gaps in the data.

Figure 8 gives a graphical indication of the daily data availability for each household (shown on the vertical axis). The households are arranged in chronological order for date of the data. The household with the earliest starting date is shown at the top of the graph with the household with the latest starting data at the bottom.

Red colours show daily data that is 100% complete, and yellow colours show daily data where there is a low fraction of the data available for that day. Days that have 0% data present, are shown in a pale yellow, which looks very similar in colour to white. The areas of Figure 8 that are white are either before the start of data collection or after the end of data collection for that particular household.

Overall, the average difference between the end of data collection and the start of data collection for the 66 houses was 368 days. However, there were many periods within the data-collection period where no data was being collected, so the average duration of available data for each household was 74 days.

Ideally, the timings of the data-collection periods for the households would be concurrent. However, the installations occurred at different times – for example, depending on the water supply authority involved. Consequently, this made it difficult to select particular periods – like summer – due to data interruptions.



Red shows periods of full data availability White indicates periods before or after data collection for that household. Yellow indicates periods when the data collection was unreliable.

Figure 8. Graph of daily data availability for each household (ID label on the left).

4.1 Total water use

Total water-use data from 66 households was collected. The interval of data collection varied as did the degree of missing data within the data files.

A winter period was taken as the average of the June data where this information was available. If the data for June was not available, an adjoining month (May or July) was used in its place. If these adjoining months had insufficient data, no estimate for the water use was made. Overall, 51 of the 66 households had winter water use identified. A histogram of the daily winter water use per household (Figure 9) shows a skewed distribution with two pronounced high outliers over 2000 L/day.

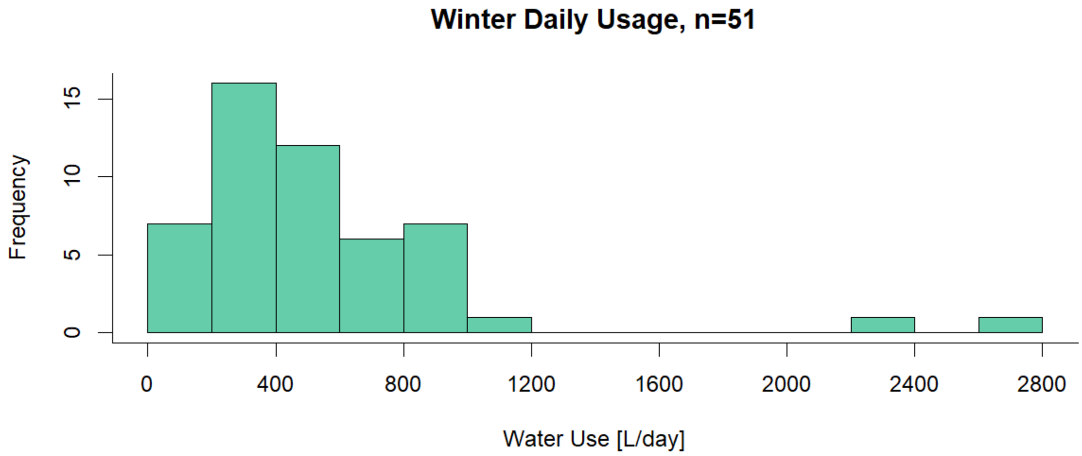


Figure 9. Histogram of the daily winter water use per house.

The average daily water use was 544 L/day with a standard deviation of 467 L/day, which equates to a coefficient of variation of 0.86. The coefficient of variation is the standard deviation divided by the mean and represents a scaleless unit of variation.

As the distribution of water use is skewed, the median (the middle value when the data is ordered) will provide a better measure of central tendency than the mean. The median for the winter daily data shown in Figure 9 is 435 L/day with a median absolute deviation (a robust replacement for the standard deviation) of 319 L/day.

As water use is seen as being driven by occupants, it is typical to consider the metric of daily water use per occupant. This metric provides a number of challenges to use with long-term measurement data. While the occupants may be surveyed and the numbers identified at the start of the monitoring, it is conceivable that the number of occupants will change over time. While this could be temporary (such as being away on holiday for a number of weeks), there could also be permanent changes (such as occupants moving out of the household). Ideally, an exit survey would be undertaken to determine a more-accurate indication of the number of occupants during the data-collection period. However, this was not undertaken as there was no fixed end date for the overall study. In addition, some data loggers stopped collecting data before the 12-month monitoring period was complete.

For the 51 houses with winter data, only 42 had occupant information. If we restrict the dataset to these 42 households, the average winter daily water use was lower at 506 L/day (or a median winter daily water use of 432 L/day) with a lower spread within the data (standard deviation of 368 L/day, coefficient of variation of 0.73 and a median absolute deviation of 319 L/day).

A histogram of the daily water use per occupant (Figure 10) shows a sharper peaked distribution, with many values occurring between 75 L/pp/day and 225 L/pp/day but a long tail of higher values. The extreme values seen in Figure 9 are less pronounced.

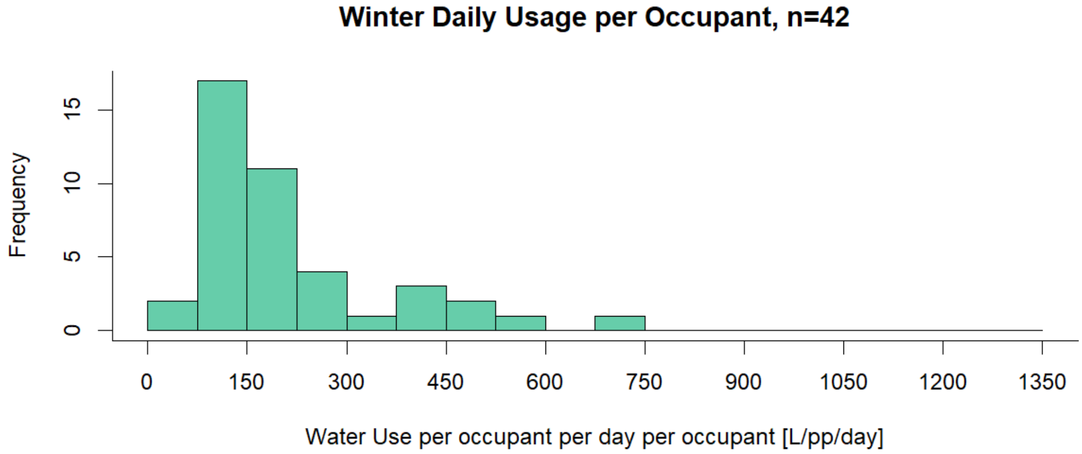


Figure 10. Histogram of daily winter water use per house per person.

The average per person water use for the winter period was 213 L/pp/day with a standard deviation of 150 L/pp/day (which has a coefficient of variation of 0.70). The median winter per person water use was 159 L/pp/day with a median absolute deviation of 84 L/pp/day.

Previous work has often reported on the 'average' (mean) water use. This has sometimes been erroneously equated to 'typical' usage. The average is overinfluenced by high water users and gives a value that is higher than typical (median) usage. The median is the middle value of the data and as such will be less influenced by the high values. The median will more accurately represent typical values. The typical value of the winter daily water use per person as reported above is roughly 25% lower than the average value.

Advice to homeowners should reference typical usage and should therefore work with median water usage. Calculating the median values requires access to the individual unit data – the initial water use for each household and the number of occupants. The average value, however, can be calculated from the total water use, which is then divided by the total number of occupants. The total water use will also measure any water losses that are occurring within the water network before the household's water meter, which will further increase the average water use as compared with the typical water use.

The summer period was taken as an average of December. Summer data is more problematic as many people take summer holidays, which is often seen in the water data as periods of zero usage. There were a number of data collection problems with the summer data (see Appendix B), so only 34 households had summer water-use information.

A histogram of the average daily water use from the 34 households for the summer period is shown in Figure 11. The average summer daily water use is 735 L/day with a standard deviation of 597 L/day, reflecting a coefficient of variation of 0.81. The median summer daily water use of 504 L/day is appreciably lower than the summer average water use, indicating the higher usage cases affecting the average. The median absolute deviation was 408 L/day, again smaller than the standard deviation.

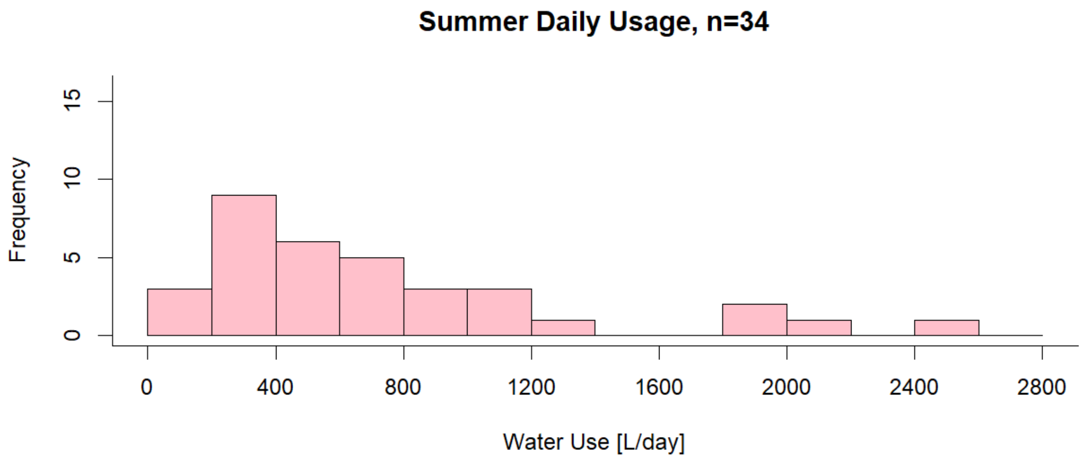


Figure 11. Histogram of the summer daily water use.

Comparing the winter and summer distributions, it appears the summer distribution has a greater number of high values (four cases over 1500 L/day from a sample of 34) as compared with the winter usage (two cases over 1500 L/day from a sample of 51).

This summer average reflects an increase of 35% over the winter average while the summer median was only an increase of 16% over the winter median.

Matching of the occupant numbers from the survey also reduced the number of cases present down to 27 for summer daily water. The summer water use also reduced to an average to 690 L/day with a standard deviation of 553 L/day (coefficient of variation 0.80). The 27 matching households had a median summer water use of 484 L/day with a median absolute deviation of 420 L/day.

The summer daily per person data is shown in Figure 12. The average water use per person over summer is considerably higher than for winter with an average of 292 L/pp/day and a standard deviation of 242 L/pp/d (0.83) with two high outliers (783 L/pp/d and 1241 L/pp/d) present within the data. The median summer daily per person usage was 231 L/pp/d with a median absolute deviation of 114 L/pp/d.

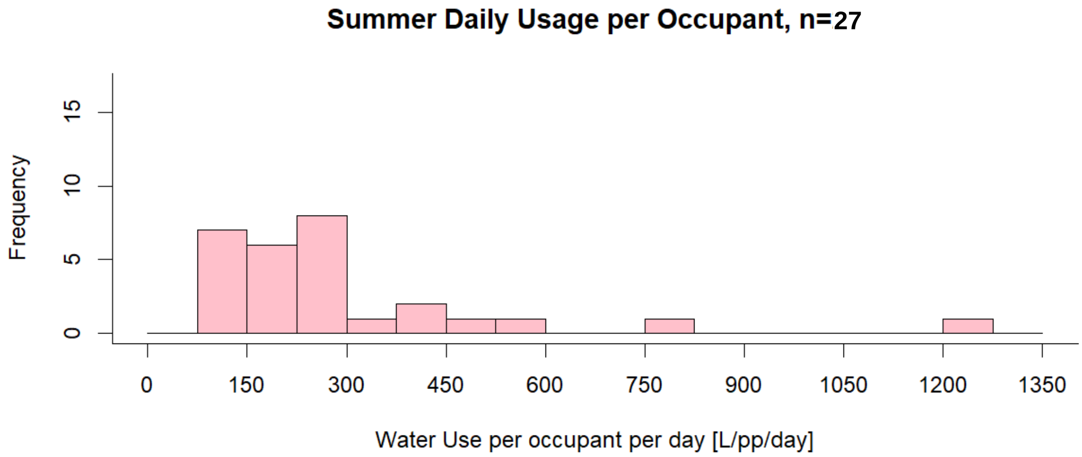


Figure 12. Histogram of summer daily water use per house per person.

This summer median reflects an increase of 37% over the winter median, which is similar to the percentage increase seen for the summer mean over the winter mean. However, the summer median per person was a 45% increase over the winter median per person water use.

It is expected that increased irrigation during summer is a driver for the increase in water use. The survey did ask a number of questions regarding outdoor irrigation including the area of the section, the area of the footprint of the house and the area of garden. The difference between the section area and the house and garden area was indicated as 'other areas' (Figure 13). While the survey asked for the area in square metres, areas were also given in hectares and acres.

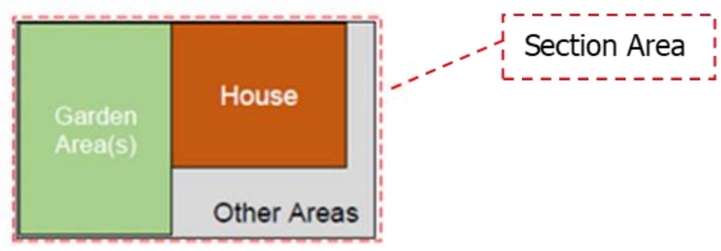


Figure 13. Various areas within the section area.

The survey was ambiguous as to what the nature of the 'other areas' were. Some respondents proportioned the section area completely between the house and the garden, leaving no area for the 'other areas'. Other responses with a large section area only indicated a small area of garden, leaving it unclear what the large area of 'other areas' comprised of. The lawn was indicated as part of the garden area but does not appear to have been included in that area by particular respondents. It is unclear from the survey and the respondents whether the 'other areas' were irrigated or were impermeable surfaces or a combination of both.

The house area was also somewhat ambiguous as some respondents presumably gave the total floor area of the home including any second storeys, as the subtraction of the house and garden area from the section area gave a negative result.

In order to examine the nature of the impacts of irrigation, the section area is used as the least-ambiguous measure of irrigated area. A histogram of the available data from 52 sites is given in Figure 14. There is clearly one section of 6978 m^2 that is much larger than the other sections, but there are two other large sections (of sizes 2000 m^2 and 2400 m^2) that are disjointed from remaining sections. While the average section size is 905 m^2, the median section area of 695 m^2 is a better representation of the typical section size.

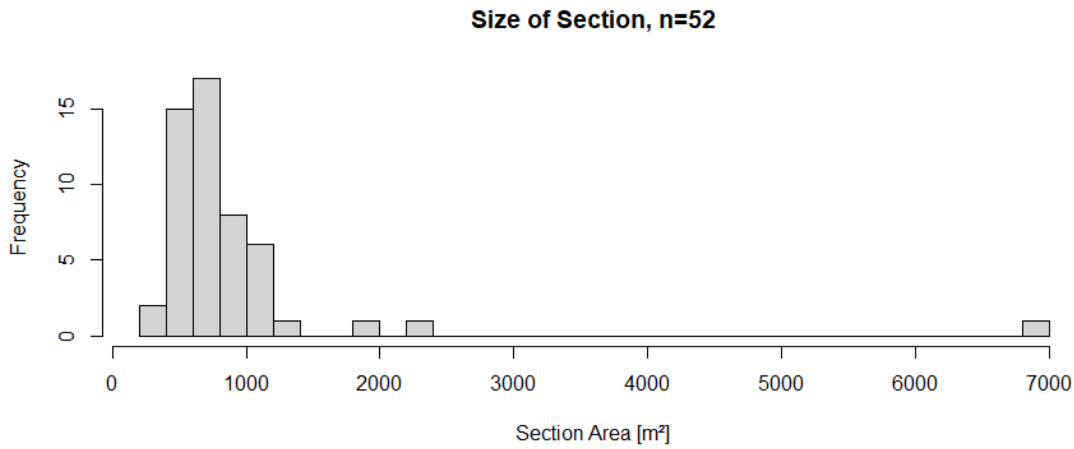


Figure 14. Histogram of the section areas for the sample.

The average daily water use (for both summer and winter) is plotted against the section area in Figure 15. As the section size doesn't change for a household, the two points for a household representing summer and winter use will be at a particular value of the section size (imaginary vertical line connecting points). This graph displays the summer and winter data independently so there are some circumstances where only one water-use value for a household is displayed such as the winter value for the household with a section size of 2000 m². Also the values for the household with a section size of 2400 m² are interesting in that the summer usage for this household is less than the winter usage for this household.

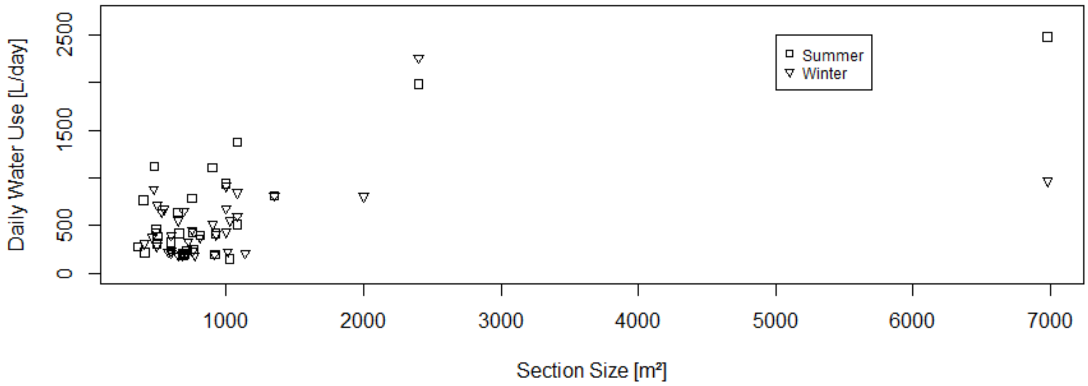


Figure 15. Daily water use in summer and winter compared with the overall section size of the property.

Figure 15 is dominated by the large section areas so the detail present in this graph is not easily distinguished. Figure 16 excludes the data from the three largest properties, providing a better view of the data.

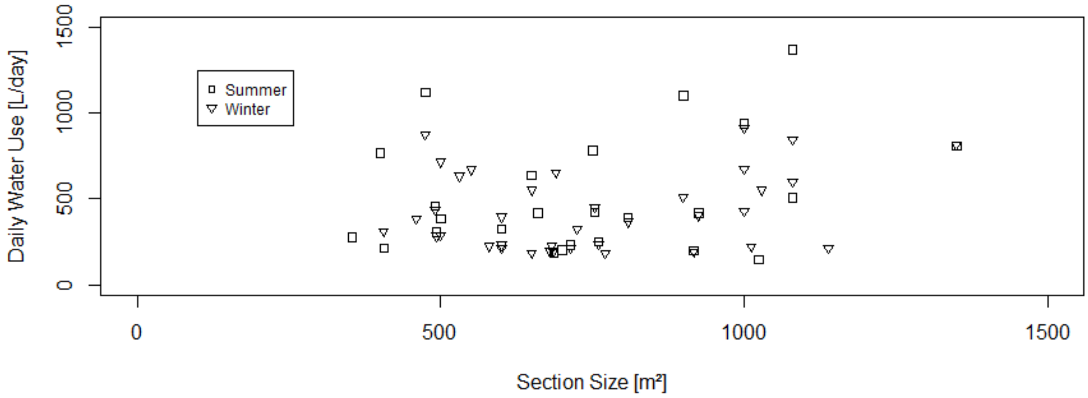


Figure 16. Daily water use in summer and winter compared with the overall section size of the property for section sizes under 1500 m².

The three largest properties provide a contrast. The largest property has a very high summer water use of 2480 L/day. However, its winter water use, while still quite high at around 966 L/day, is comparable to other households with much smaller section areas. This household is in a metered and volumetrically charged area. The second-largest property has consistently high water use for both winter and summer with the added quirk that winter water use is actually higher than summer water use. This household is in an urban area that does not have metering in place. The third-largest property represents a bit of an unknown as summer water use information for this household was not able to be collected. Water use for the winter data was high at 804 L/day. The household is in a metered rural area that undertakes volumetric charging.

It is likely the best estimate for summer water use is winter water use – a scatter graph of these two values is shown in Figure 17. A straight line through these data points would account for around 65% of the variation present within the data. Transforming this data by taking logarithms would improve the variation described up to 82%.

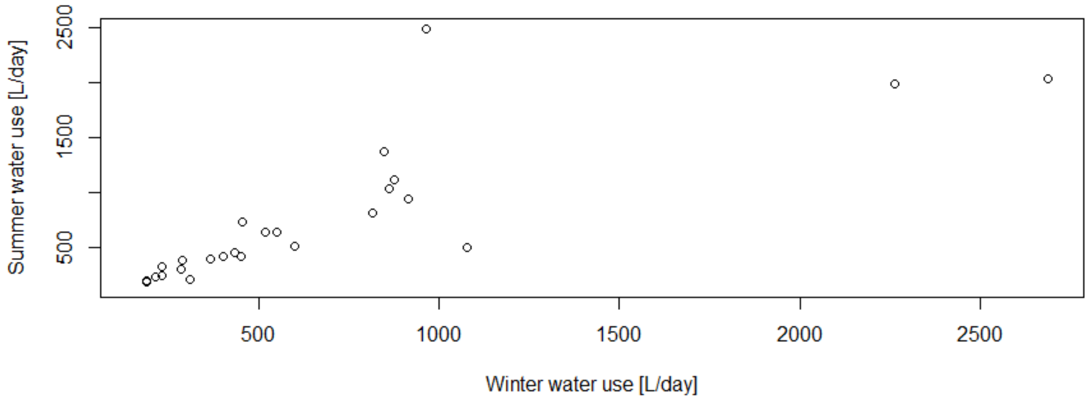


Figure 17. Comparison of summer water usage with winter water usage.

4.2 End-use extraction

Understanding the drivers of water use within a home is typically improved by better understanding the components or end uses for the water use. Typical end uses include toilets, showers, taps, dishwashers, washing machines, leaks and outdoor irrigation. Appendix A provides a brief introduction to end-use extraction methods.

In the previous WEEP (Heinrich, 2007) and AWUS projects (Roberti, 2010), the Trace Wizard software program was used to provide these end uses. Attempting to apply the Trace Wizard program to the current study presented several difficulties. In order to assign water use to various end uses, a site visit is required to complete an audit of appliances and fittings. This visit would collect the characteristic drawn-off (signature) patterns for each appliance one at a time. A trial of the audit visits was conducted in one region. The spread-out nature of the sample together with the longer than expected time to use the Trace Wizard tool meant that it was not practical to use Trace Wizard for the full sample.

Through discussions with Water New Zealand and various other stakeholders, the value of including the water end-use information for this dataset was reinforced.

Colin Whittaker, Teresa Scott and Kobus van Zyl from the Department of Civil and Environmental Engineering at the University of Auckland had previously been provided with example data to evaluate for their research. They are now investigating the potential to extract end-use information using a variety of approaches and have been provided with the full residential water-use dataset. This work will be publicly reported separately (Whittaker, Scott & van Zyl, 2022).

4.3 Water Efficiency Labelling Scheme

The Water Efficiency Labelling Scheme (WELS) began development in Australia in 2005 (GHD, 2006) and was adopted in New Zealand regulations in 2010 with a later update taking place in 2017 (Ministry for the Environment, 2019).

The survey forms (see Appendix C) asked respondents what the WELS ratings were for their various appliances and fittings.

The primary purpose of the WELS label is to steer purchasers towards water-efficient appliances at the time of purchase. The continued presence of the WELS rating labels may have some ongoing benefit of greater awareness of water efficiency and, more specifically, the performance level achieved by the labelled appliance.

While section 4.4 reports on the WELS ratings for each type of appliance, the overall number of responses were low. This could be due to many reasons – the appliance pre-dated the WELS scheme and was not rated, the WELS label had been removed and the householder didn't remember or know what the rating was or the householder didn't know what the WELS rating referred to and left the answer blank.

4.4 Water uses

4.4.1 Toilets

Survey responses on toilets were received from 56 households. Within these households were 107 toilets with the numbers per house shown in Figure 18, which shows a peak at two toilets per household.

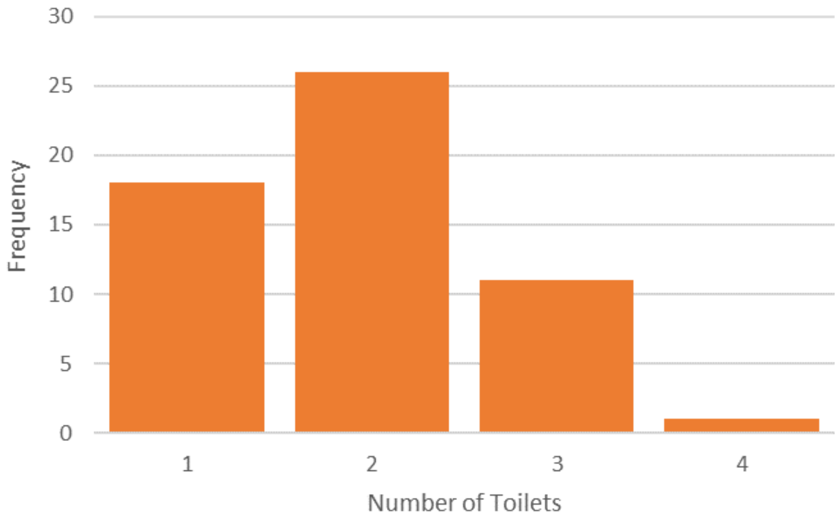


Figure 18. Histogram of the number of toilets per household.

Less than 10% of the toilets had a WELS star rating given, with the numbers reported in Table 2. As many of the households had multiple toilets, only five households reported the WELS star rating of their toilets.

Table 2. WELS star ratings for toilets.

	Star rating				
	Not reported	3	3.5	4	4.5
Number of toilets	97	3	0	6	1

Dual-flush toilets were the dominant type with 94 identified. Of the 13 single-flush toilets, eight were large with the remaining five small.

The small numbers of large single-flush toilets together with the large number of dual-flush toilets is encouraging from a water efficiency point of view.

4.4.2 Showers

Slightly fewer households (53) reported on the number of showers they had. One shower per household was the most popular number with the distribution of numbers per house shown in Figure 19. Overall, 85 showers were present.

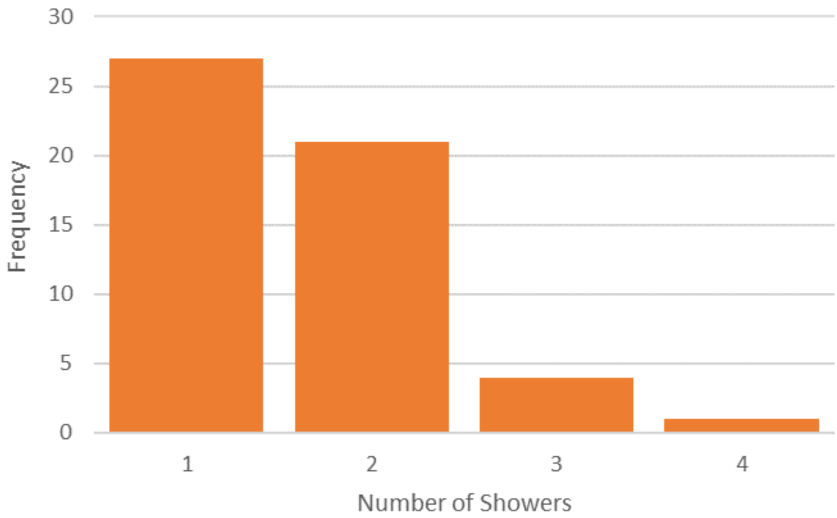


Figure 19. Histogram of the number of showers per household.

Only three households reported WELS star ratings for the showers with one each reported for 1 star, 2 stars and 3 stars.

The average reported length of water use for each shower was approximately 7.5 minutes. This average should be used with caution. Often a range of times were reported for this duration question (for example, 5–10 minutes) for which a mid-point was used. Two of the 53 households also did not answer this question.

Likewise, the number of uses of the showers per week was also often answered as a range of values, and again the mid-point was used in the calculations. Figure 20 shows a histogram of the number of uses of the shower per household with a peak of between 5–10 uses per shower per week.

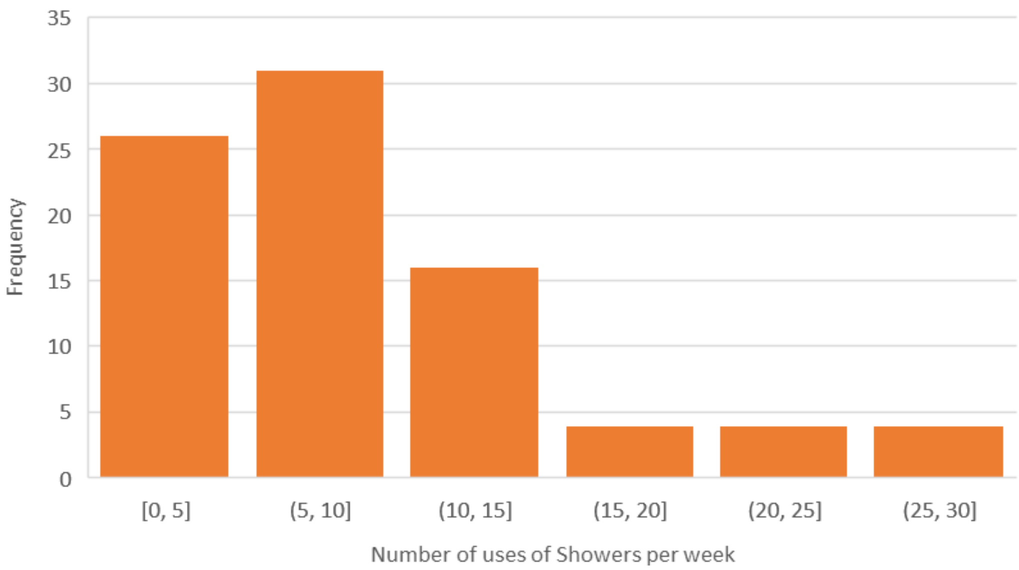


Figure 20. Histogram of the number of uses of showers per week.

4.4.3 Dishwashers

Around three-quarters of the homes with survey responses (65 for this question) had a dishwasher.

The average number of loads per week (using the mid-points for any ranges) was 4.6 loads per week.

4.4.4 Hand basin taps

Overall, 56 households had information on hand basin taps. The distribution of the numbers per household is shown in Figure 21.

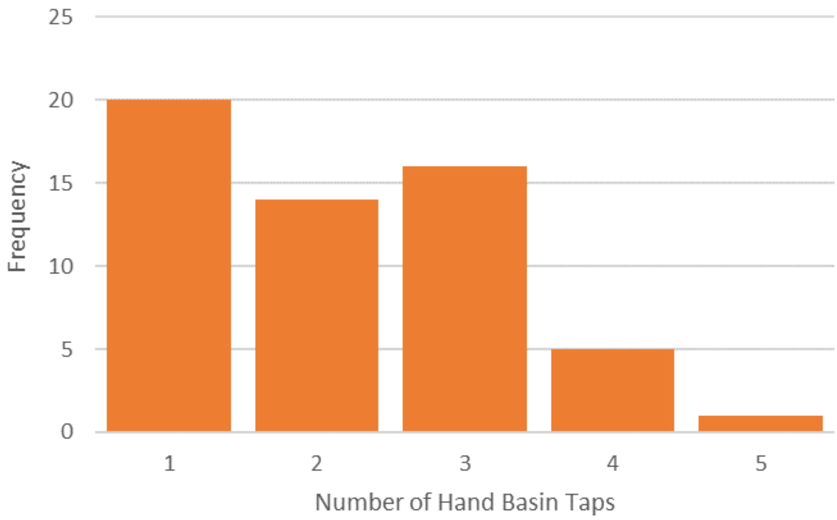


Figure 21. Histogram of the number of hand basin taps per household.

Again, the WELS star ratings (see Table 3) were often omitted, with only seven of the 121 taps having a rating value provided.

Table 3. WELS star ratings for hand basin taps.

	Star rating			
	Not reported	**2**	**3**	**4**
Number of hand basin taps	114	5	0	2

4.4.5 Washing machines

Of the 56 households reporting washing machines, 20 (36%) had front-loading machines. This represents a major shift in appliance use. For the Auckland Water Use Study in 2008 (Roberti, 2010) only 6% of the households had a front-loading washing machine.

The average age of washing machines for the 47 households reporting data was 5.6 years (see Figure 22).

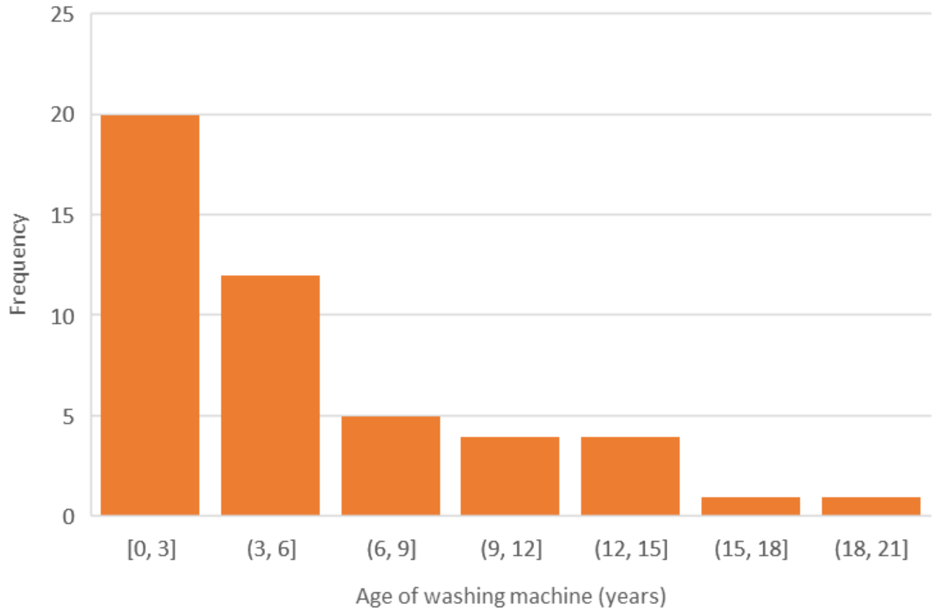


Figure 22. Histogram of the age of washing machines.

Again, the reporting on the WELS star ratings was low. While the majority of washing machines were less than 6 years old, only 10 households reported the WELS star rating for their washing machine (see Table 4).

Table 4. WELS star ratings for washing machines.

	Star rating						
	Not reported	**1**	**2**	**3**	**3.5**	**4**	**4.5**
Number of washing machines	46	1	1	2	1	2	3

The number of loads per week averaged 5.0 for the 49 households that provided this information. Again, sometimes ranges were given in response to this question and the mid-point was used for the calculation of the average.

Front-loading washing machines generally use less water than top-loading washing machines, and this change of appliance type over time represents a potential water efficiency improvement. Quantifying the size of this improvement would require information on the washing machine water end-use within each home, which is being further investigated by the University of Auckland (see section 4.2).

4.4.6 Other water uses and sources

The increased water use seen in summer in many houses is often attributed to garden irrigation.

The variation between summer and winter water use can be large. Looking more specifically at the summer water-use patterns, a number of homes showed extended periods of high water use especially in the early mornings, presumably to reduce evaporative losses. These are likely due to the operation of sprinkler systems. From the 54 households reporting data, around 28% of households reported they had some type of sprinkler system. As shown in Table 5, these systems were approximately evenly distributed between automated systems and manual systems

Table 5. Types of irrigation systems.

None	Manual sprinkler	Automated sprinkler
39	8	7

Leakage from within the householder's side of the water supply is difficult to assess. There are a couple of events within the 66-household dataset that indicate significant leaks. There is also potential to further examine the detailed time series to see the potential effect of small leaks within the home. Leakage is an additional topic that the University of Auckland will examine for this dataset.

In the 57 households with information present, five households (under 10%) indicated they had a rain tank. These tanks were varying sizes, as shown in Table 6. These five households all used the rainwater solely for garden irrigation.

Table 6. Rain tank sizes.

Size of rain tank (in litres)	120	200	480	750	3000

None of the 57 households had a greywater recycling system.

Other interesting water uses were one household with a 30,000 litre swimming pool and three households with spa pools.

5. Outcomes

Data on water use was collected from 66 households from around the country.

This data consisted of a finely resolved total water use for the household measured at 10 second time intervals and a survey of the occupants and their water-using fixtures and appliances (see the survey forms in Appendix C).

The **average** water use observed was:

- 213 litres per person per day for winter
- 292 litres per person per day for summer.

The histogram of daily water use showed a prominent skew with most values occurring at values lower than the average water use. The tail of high values was extended with many high values occurring within the data. The average would therefore be higher than it should be as it would be influenced by these higher values.

This situation indicates that the average is not a reliable indication of central tendency and that the median would be a better measure. The median would more closely represent what a 'typical' household may use.

The **median** water use observed was:

- 159 litres per person per day for winter
- 231 litres per person per day for summer.

This median water use is 25% lower than the average water use in winter, while in summer, the median is 21% lower the average.

The large difference between summer and winter water use has traditionally been attributed to summer irrigation. The larger-sized properties did seem to have an increased likelihood of being a higher water-using household.

Rather than using previous assumptions about how water use should be attributed, the assignment of water use into end uses (such as toilet, shower, washing machine and outdoor irrigation) may provide an insight into how water use has changed or differs.

Assigning water use to end uses is a difficult process. A number of approaches are discussed in Appendix A. The Trace Wizard approach was intended to be used for this project. However, with a number of data-collection issues occurring, the end-use disaggregation was not completed.

Colin Whittaker, Teresa Scott and Kobus van Zyl from the Department of Civil and Environmental Engineering, Faculty of Engineering at the University of Auckland have been provided with the complete residential water use dataset so they can investigate the opportunities to determine the end-use disaggregation for the dataset.

A survey was completed by each household and provided a range of information on the occupants, their water-using appliances/fittings and how these appliances/fittings are used.

Many respondents were not aware of the Water Efficiency Labelling Scheme (WELS) star rating of their appliances/fittings. The appliance with the highest proportion of star ratings known was the washing machine with 18% of homeowners aware of the star rating.

The washing machine is an appliance type that has changed considerably since the AWUS study (Roberti, 2010) where less than 6% of households had a front-loading washing machine. This project has seen the ownership of front-loading washing machines increase to 36%. As front-loading washing machines can have much lower water consumption than top-loading washing machines, this could represent a good water savings potential.

Only five of the 57 households reporting data (less than 10%) had a rain tank of any size, so there remains a large potential to increase the number of rain tanks present.

The amount of water used for outdoor irrigation can be large. Around 28% of homes had a sprinkler system with these roughly split between automatic and manual systems.

References

Armel, K. C., Gupta, A., Shrimali, G. & Albert, A. (2013). Is disaggregation the holy grail of energy efficiency? The case of electricity. *Energy Policy*, *52*, 213–234.

Bayne, K., Jaques, R., Lane, A., Lietz, K. & Allison, R. (2005). *NOW Home protocols: A toolkit documenting the Beacon approach to sustainable residential design*. Auckland, New Zealand: Beacon Pathway.

Booker, D. J. & Henderson, R. D. (2019). *National water allocation statistics for environmental reporting; 2018*. Christchurch, New Zealand: NIWA.

Cominola, A., Giuliani, M., Castelletti, A. Piga, D. & Rizzoli, A. (2015). Benefits and challenges of using smart meters for advancing residential water demand modeling and management: A review. *Environmental Modelling & Software*, *72*, 198–214.

Conder, T. (2008). *Water*. Level Sustainable Building Series. Judgeford, New Zealand: BRANZ Ltd.

Controller and Auditor-General. (2018). *Managing the supply of and demand for drinking water*. Wellington, New Zealand: Office of the Auditor-General.

French, L., Heinrich, M., Jaques, R., Kane, C. & Pollard, A. (2007). *Waitakere NOW Home performance monitoring: Year one report*. Technical Report NO102/3. Auckland, New Zealand: Beacon Pathway.

Froehlich, J., Larson, E., Campbell, T., Haggerty, C., Fogarty, J. & Patel, S. (2009). HydroSense: Infrastructure-mediated single-point sensing of whole-home water activity. In *Proceedings of the 11th International Conference on Ubiquitous Computing* (pp. 235–244). New York, NY: ACM.

Froehlich, J., Larson, E., Saba, E., Campbell, T., Atlas, L., Fogarty, J. & Patel, S. (2011). A longitudinal study of pressure sensing to infer real-world water usage events in the home. In K. Lyons, J. Hightower & E. M. Huang (Eds.), *Proceedings of the 9th International Conference on Pervasive Computing* (pp. 50–69). Berlin, Germany: Springer-Verlag.

Garnett, A. & Sirikhanchai, S. (2018). *Residential water tariffs in New Zealand*. BRANZ Study Report SR413. Judgeford, New Zealand: BRANZ Ltd.

GHD. (2006). *Scoping study to investigate measures for improving the water efficiency of buildings*. Canberra, Australia: Australian Greenhouse Office, Department of the Environment and Heritage.

Gourmelon, N., Bayer, S., Mayle, M., Bach, G., Bebber, C., Munck, C., Sosna, C. & Maier, A. (2021). Implications of experiment set-ups for residential water end-use classification. *Water*, *13*(2), 236.

Heinrich, M. (2006). *Residential water end use literature survey*. BRANZ Study Report SR149. Judgeford, New Zealand: BRANZ Ltd.

Heinrich, M. (2007). *Water End-use and Efficiency Project (WEEP) – final report*. BRANZ Study Report SR159. Judgeford, New Zealand: BRANZ Ltd.

Isaacs, N., Camilleri, M., Burrough, L., Pollard, A., Saville-Smith, K., Fraser, R., Rossouw, P. & Jowett, J. (2010). *Energy use in New Zealand houses: Final report on the Household Energy End-use Project (HEEP).* BRANZ Study Report SR221. Judgeford, New Zealand: BRANZ Ltd.

James, B., Saville-Smith, N., Saville-Smith, K. & Isaacs, N. (2018). *Doing better in residential dwellings: Going beyond the Code in energy and accessibility performance*. BRANZ External Research Report ER27. Judgeford, New Zealand: BRANZ Ltd.

Kaye-Blake, B., Schilling, C., Nixon, C. & Destremau, K. (2014). *Water management in New Zealand: A road map for understanding water value*. Wellington, New Zealand: NZIER.

Larson, E., Froehlich, J., Campbell, T., Haggerty, C., Atlas, L., Fogarty, J. & Patel, S. N. (2012). Disaggregated water sensing from a single, pressure-based sensor: An extended analysis of HydroSense using staged experiments. *Pervasive and Mobile Computing*, *8*(1), 82–102.

Lawton, M., Birchfield, D. & Wilson, D. (2008). *Slowing the flow: A comprehensive demand management framework for reticulated water supply*. Auckland, New Zealand: Beacon Pathway.

Ministry for the Environment (2009). *On tap? Attitudes, behaviours, and perceptions of household water use – informing demand management*. Wellington, New Zealand: Ministry for the Environment.

Ministry for the Environment. (2017). *Briefing to the incoming Minister for the Environment – water issues*. Wellington, New Zealand: Ministry for the Environment.

Ministry for the Environment. (2019). *Information for suppliers and style guide for the New Zealand Water Efficiency Labelling Scheme*. Wellington, New Zealand: Ministry for the Environment.

Ministry of Business, Innovation and Employment. (2020). *Transforming operational efficiency*. Wellington, New Zealand: Ministry of Business, Innovation and Employment.

New Zealand Business Council for Sustainable Development. (2008). *A best use solution for New Zealand's water problems*. Auckland, New Zealand: New Zealand Business Council for Sustainable Development.

Pastor-Jabaloyes, L., Arregui, F. J. & Cobacho, R. (2018). Water end use disaggregation based on soft computing techniques. *Water*, *10*(1), 46.

Pollard, A., French, L., Heinrich, M., Jaques, R. & Zhao, J. (2008). *Waitakere NOW Home performance monitoring: Year two report*. Technical Report NO102/4. Beacon Pathway, Auckland, New Zealand.

Pollard, A. R. (2010). *The performance of residential water heating in New Zealand.* Paper presented at New Zealand Sustainable Building Conference (SB10), Wellington, New Zealand, 26–28 May.

Roberti, J. (2010). *Auckland Water Use Study – monitoring of residential water end uses*. Paper presented at New Zealand Sustainable Building Conference (SB10), Wellington, New Zealand, 26–28 May.

Schultz, P. W., Messina, A., Tronu, G., Limas, E. F., Gupta, R. & Estrada, M. (2016). Personalized normative feedback and the moderating role of personal norms: A field experiment to reduce residential water consumption. *Environment and Behavior*, *48*(5), 686–710.

Stewart, G. (2009). *The case for demand management in council water supplies*. Wellington, New Zealand: Water New Zealand.

Water New Zealand. (2020). *National Performance Review 2019–2020*. Wellington, New Zealand: Water New Zealand.

Water New Zealand. (n.d.). *Water metering.* Wellington, New Zealand: Water New Zealand.

Whittaker, C., Scott, T. & van Zyl, K. (2022). *Residential water use in New Zealand – end use disaggregation*. Auckland, New Zealand: Department of Civil and Environmental Engineering, Faculty of Engineering, University of Auckland.

Appendix A: End-use analysis[6]

Determining how water is used within a home is tricky. Installing separate meters for each water use was the approach used in Beacon Pathway's NOW Home (French et al., 2007; Pollard et al., 2008), but this method proved to be complicated and costly and would not be suitable for existing homes. Using a high-resolution water meter to allow for the individual uses of water to be determined from their characteristic usage patterns (disaggregation) has been seen as the 'holy grail' for efficiency efforts (Armel, Gupta, Shrimali & Albert, 2013). Being able to identify the components of water use allows for more-appropriate targeting of efficiency and management efforts.

This appendix provides a brief introduction to a variety of end-use analysis methods and concludes with some comments about generic approaches.

A.1 Trace Wizard

Trace Wizard analyses water-use data recorded from loggers connected to water meters. The water-use data is then disaggregated using Trace Wizard into discrete water-use events, calculating critical information such as the volume and flow rate of each event. Fixture designations such as "toilet" or "shower" are assigned to each water use based on user-defined sets of parameters and recorded as different colours on a graph.

Trace Wizard applies a decision tree algorithm to interpret metered flow data based on some basic flow boundary conditions (Cominola et al., 2015). It is suggested that analysts use water audits, diaries and sample flow trace data for each household to create specific templates that serve to match water end-use patterns depending on those basic flow boundary conditions. Individual water end-uses are disaggregated based on the developed templates, stock survey audits, diary information and analyst experience.

However, the human resource effort required by Trace Wizard makes the overall process extremely time and resource intensive, with the quality of the results strongly dependent on the experience of the analyst in understanding flow signatures (Cominola et al., 2015). It has been estimated that the classification of 2 weeks of data requires approximately 2 hours' work by the analyst and attains an average classification accuracy of 70%. Further, the prediction accuracy is significantly reduced when more than two events occur concurrently. Regardless, it "has an edge on disaggregation techniques and has been used in several research works and projects" (Cominola et al., 2015, p. 6).

A.2 Identiflow

The Identiflow system comprises of a flow meter and logger system installed in an external meter box and the Identiflow software, which contains an automatic facility that assists in identification and classification of micro-component events. An interactive facility is also contained, which permits review and refinement of the analysis.

Identiflow does not require calibration for each site, and therefore customers' consumption can be monitored without influencing their behaviour. Identiflow uses

[6] This section uses material prepared by Riaan Labuschagne.

fixed physical features of various water-use devices such as the volume, flow rate and duration to classify the end-use events (Cominola et al., 2015).

Although Identiflow shows better accuracy than Trace Wizard at 74.8% classification accuracy, this strongly depends on the physical features used to describe each fixture or appliance measured (Cominola et al., 2015). Also, two different water events are likely to be classified into the same category if they exhibit similar physical characteristics. Further, there is a risk that Identiflow may fail to classify events when old devices are replaced by modern ones as the physical characteristics of the devices might be completely different.

A.3 HydroSense

HydroSense systems can be installed at any accessible area within a home's existing water (Froehlich et al., 2009, 2011; Larson et al., 2012). The systems can be installed with simple screw-on installation points, with no need for a plumber. HydroSense's analysis of pressure provides the capability of sensing both the individual fixture at which water is currently being used as well as an estimate of the amount of water being used. The sensing of pressure is also less susceptible to ambient noise.

HydroSense works as a probabilistic-based classification approach, which relies on data collected through pressure sensors (Cominola et al., 2015). When water valves are opened and closed, a pressure change occurs and a pressure wave is generated in the plumbing system. Advanced pattern matching algorithms and Bayesian probabilistic models are used to match the pressure wave to a specific end-use event.

HydroSense has shown high levels of classification accuracy, with 90% accuracy if one pressure sensor is used and 94% if two pressure sensors are used (Cominola et al., 2015). However, the calibration of the algorithm requires an intrusive monitoring period as a large number of pressure sensors need to be installed and connected to each water device. This limits the viability of HydroSense in a large sample due to the costs involved and privacy issues.

A.4 BuntBrainForEndUses

BuntBrainForEndUses is a commercial software that can be used for water end-use analysis (Pastor-Jabaloyes, Arregui & Cobacho, 2018). It is an online software package that offers the possibility of exporting raw flow traces and importing them back after some manipulation has been carried out. This allows for developing specialised filters and disaggregation algorithms that are independent from BuntBrainForEndUses. The results from those filters and algorithms can then be displayed and corrected in the online application.

A.5 General artificial intelligence methods

In the last few years, there has been an increased interest in applying general artificial intelligence techniques to the problem of determining the components of residential water use. This is a technical and data-intensive field with a multitude of options. Gourmelon et al. (2021) recently published a comparison of various machine-learning techniques when applied to the same dataset.

Appendix B: Lessons from the data collection

This project differed from other measurement projects that BRANZ has been involved with in that the equipment provision, installation and data collection was intended to be largely provided by third parties.

An extensive stakeholder engagement process was undertaken with members of the water supply authorities seeking to have their participation within the project. Their participation would involve selecting a sample of properties from within their customer base that was in proportion to their population relative to the rest of New Zealand. With an overall sample size of 300 high-resolution households throughout the country, the numbers for individual council areas ranged from 86 for Auckland to the low 30s for Wellington and Christchurch down to one or two for many of the smaller councils.

Participation request forms and a household survey (see Appendix C) were coordinated between BRANZ and the water supply authority.

The water supply authorities were to purchase recommended water metering (there was also provision for equipment to measure daily water use) from the meter/logger providers. The water supply authorities were able to increase the number of meters deployed in their areas so that more-accurate data could be collected from their region.

The councils were to also contract the data providers to collect the data from the water meters and provide this back to the councils on a regular basis. BRANZ would also receive a copy of this data from the data providers. Initially, one data provider was used, but a second data provider was also used towards the end of the data-collection period. The experiences related here primarily relate to the first data provider. One water supply authority managed the data collection separately and provided data directly to BRANZ. A change in staffing half-way through the data-collection period resulted is a change of data format from this water supply authority.

As is evident from Table 1, there was a drop-off from those households completing the surveys and those that were instrumented. One of the reasons for this was that several water supply authorities who were happy to participate in the selection and household surveying chose not to continue with the study when the meter purchasing and data provision contracts were required.

Overall, the participation from the larger water supply authorities was low. Many of the water supply authorities had only one or two high-resolution water meters/loggers within their area, which made some of the stakeholder engagement difficult. There were a number of times where the point of contact with the water supply authority changed with little information about the project passed on to the new contact person.

B.1 Equipment installation

The equipment to be installed comprised of a high-resolution water meter with a pulse output via a cable. This cable was then fed in to a battery-powered data logger with an integrated cellular modem that allowed the data to be transferred back to the data providers. The water meter was to be placed on the council side of the property boundary in an in-ground meter box. Where an existing meter was in position, the high-resolution meter replaced or was placed in series with this meter.

The installation of the water meter and data logger was arranged between the water supply authority and the meter/data provider. As only a few water meters were required to be installed in many areas, most water supply authorities had their own staff install the water meters and attach the data loggers. This was a false economy. As the council installer typically only did fewer than four installs, they didn't build up an experience with the set-up. As the data logger had a cellular modem within it, it was critical that it be securely mounted in an appropriate vertical orientation so that it would be able to transmit a reliable signal. The data logger was a tubular shape and lacked a documented method (or appropriate attachment hardware) to securely position the data logger within the meter box.

As the data loggers used a cellular connection, it was critical to ensure that data could reliably be received by the data provider. The placing of the data logger in a meter box in the ground was detrimental to the cellular signal. As many of the smaller installations were in remote areas, the cellular signals were often substandard.

One example of the importance of the set-up arrangements was of a city council that had five meters installed across the city. While these meters produced good signals with no data interruption at the time of the installation, over the course of a week several months later, all of the meters started to have communications problems, the signal level dropped dramatically and there were data interruptions despite the battery levels for the loggers remaining high. As all these sites were independent, the presumption is that an event such as regular meter readings caused these communication difficulties. The propping up of the data loggers may have been done carefully (but not fixed in a permanent way) at the installation but the disturbance at the time of the meter reading may have resulted in the logger falling down and lying horizontally in the bottom of the meter box and failing to provide a reliable signal. It is important that clear information is given to those engaging with the meters (meter-reading team) at a later time including signage to reduce the chances of the loggers being disturbed.

The data loggers were supplied with SIM cards that allowed connection to only one cellular company. Installation staff were asked to check the strength of the cellular connection by using their cellphone (provided that it was for the same cellular provider) to determine the strength of connection at the site. Often the installer did not have a cellphone for the required cellular provider so this check was omitted altogether. The lack of rigour in confirming that the site had sufficient cellular signal strength was a weakness of the installation process and resulted in data loss within the project.

The data logger also provided no way for the installation team to test the data connection once the installation was complete. This could be a problem with remote sites. If the signal received is not very good, if would be useful to identify whether making adjustments to the logger positioning could assist. The loggers receive a large amount of data, so to ensure that the loggers don't have their memories fill up too quickly, the data loggers were set to upload their data every 6 hours at 00:00, 06:00, 12:00 and 18:00. The noon upload of data could provide a limited ability to check on a morning's installation in the afternoon, but in reality, checking on the success of a meter installation was done a day or two after installation had taken place.

When data was confirmed as being collected from a site, the site was regarded as 'installed' regardless of the quality of the signal strength. There were a number of cases where the data logger would collect data for a short period of time (days or weeks) and then stop. This was presumably from changes in the environment for the cellular signal such as the logger falling over or cars being parked near the meter box.

For locations with a persistent poor cellular signal, there were few mitigation steps available. With the data provider being locked in to one cellular provider, there was not an ability to see if alternate cellular companies had better coverage at that location. The positioning of the logger within the ground in a meter box was also a problem as it is not an ideal position for a cellular signal. While the meter had to be placed in the ground, it could have been an option to mount the logger (or an aerial attached to it) in a higher, more suitable location. The in-field work was also generally carried out by the water supply authority, which had limited visibility of cellular signal strengths.

The two initial sites used originally for testing purposes were in areas with good cellular reception. For future projects, testing should be more extensive and include more-challenging situations such as areas with marginal cellular reception.

For future projects, it is also recommended that the confirmation of data being received back from an installation is not sufficient for the installation to be regarded as complete. Prior to the installation of the data collection equipment, a site should be assessed that it will be suitable for the full duration of the experiment. This should include signal strength measurements when cellular services are relied upon.

B.2 Battery life

It was thought that battery life of the data loggers would not be a problem for the duration of the study. The data loggers used a large-capacity lithium battery that was not intended to be replaced by the users. The product literature for the logger stated that the battery life was in the order of 5 years. However, this lifetime related to the unit collecting data at 10 minute sampling intervals. Operating the loggers at 10 second intervals, as required for the project, had a major impact on the battery life of the loggers. Many batteries were depleted after around 8 months of monitoring. A key aspect of water use that was to be examined was the change of water use throughout the year, and the 8 months of data collected was not sufficient to identify how water use was changing over the year or to provide reliable annual water-use figures. Many of the meter/logger installations occurring in autumn resulted in the batteries being depleted just before the increase in water usage over summer.

Battery replacement involved disconnecting the logger from the meter and returning the logger to the logger/data provider. The battery was of a non-standard type and was likely expensive and difficult to obtain. However, a bigger problem occurred with the non-functionality of the logger after the battery was replaced. This was a point of contention between the logger/data provider and the logger manufacturer with the manufacturer refusing to take responsibility for the faulty logger units and blaming the logger/data provider. No replacement loggers were provided for loggers that became non-functional after the battery was replaced with the sample reducing in size over time.

B.3 Data file management

The intention of this project was that data management – raw data collection and checking that data was coming in from each site and that the data made sense – was going to be provided by the logger/data provider on behalf of the water service provider and that a copy of the data would be provided to BRANZ to collate for all the regions, compare with the occupant survey information and provide a summary report.

BRANZ was not a party to the agreements between the logger/data provider and the various water service authorities.

The raw data from the loggers consisted of a text file containing 6 hours of data from each logger. The file was named with the logger serial number and a date stamp. At the bottom of this text file was a battery percentage and a signal strength indicator.

While the short files created numerous files (there were over 64,000 files), this in itself would not have been a problem. However, the files were quite inconsistent. The fixed duration of the monitored period meant that the files should have all been of the same size. However, around 8% of the files were bigger than the standard size and around 9% were smaller. If the logger was unable to transfer the files at the set time, the logger would send a larger file at the next 6-hour block.

A complete file had no header and just had a time stamp, a pulse reading and a pressure reading (which was ignored). At the end of the file, the last line would include the battery status and signal strength as two additional fields.

Many of the shorter files had the file line terminate in a random place within the file. These files had no battery status or signal strength recorded. Sometimes, the interruption occurred part-way through the time stamp introducing a high degree of randomness into the process.

Other problems emerged as the data was examined more closely. Time stamps were seen that had dates in the past or the future. Some data had more pulses that the meter was physically capable of recording, and there were extended periods of zero pulses for some loggers.

These data collection issues resulted in BRANZ taking a more involved role in examining the data from individual households. This included tracking battery levels and signal strengths and reporting this back to the water supply authority and the meter/data provider.

Resolving these issues was not always straightforward. While it could be identified that data was not being received from a particular site, a visit to the site may not be able to identify any specific issue, with the problem with the data being put down to low signal strength for the site. These marginal signal strength sites should have been excluded early so that more effort could have been focused on those households with a good amount of data.

B.4 Data formats

The water supply authorities also received copies of the raw data. One council commented that this data was not what they were expecting as there was no way to automatically filter or summarise the data. While the 10 second time series raw data produces far too much data information to immediately feed in to display tools such as dashboards or interactive graphics, there is an increasing expectation that this type of summary data is available to explore the data.

One water supply authority did provide the raw data from the data loggers deployed in its region. This was initially supplied as a monthly spreadsheet with the data from the various households (loggers) as columns with a common timebase in the first column.

Towards the end of this file, the time was no longer synchronised for some of the loggers. This resulted in some of the loggers reporting at 10 second intervals but offset by 5 seconds. This resulted in a timebase that was no longer 10 seconds apart but 5 seconds apart with extensive blank cells in the data area. These blank cells do not represent missing data but indicate that mismatching of the data is occurring.

Half-way through the data collection at this water supply authority, the person responsible for collating the data left. After the handover to the new person, the format of the data changed to a weekly text file export. This required a new importing process to be developed. While this is straightforward when the structure is simple, problems such as the blank data and misaligned timesteps can require additional effort to be spent on the data-importing stage.

Appendix C: Survey data

In addition to the water-use measurements within each of the households, the households were asked to complete a survey of their water-using appliances and hot water systems, details of the property and outdoor irrigation practices as well as background information on the occupants. The survey forms used within this project are shown on the following pages.

Residential Water Use Study – QUESTIONNAIRE

Please answer the below questions as best you can, and only the questions you're comfortable answering

---

Q1: WATER USE details:

a: Please estimate how much water you think your household uses each day: .... litres per day

How did you estimate this?...

....

....

....

....

....

....

b: How high do you think this estimated daily water use is: (circle one) **HIGH** **MEDIUM** **LOW**

c: Do you know of any LEAKS on your property? ....**What/Where?**..

....

....

d: Do you have any DRIPPING taps or toilets? ....**What/Where?**..

....

....

e: Over the last 3 years, please tell us where (and what) SIGNIFICANT EVENTS occurred that may have affected your water use? (e.g. away over 2013/2014 Christmas period, fill swimming pool in November each year, identified a leak in December 2015, or installed low flow shower head and new toilet in August 2011, had a baby in January 2013, or upgraded the washing machine in May 2016)

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- - PLEASE NOTIFY US IF ANYTHING CHANGES DURING THE MONITORING PERIOD - -

Q2: BATHROOM Water Use:

a: Please tell us about the TOILET(S) in your home using the boxes provided below:

WELS ratings are listed on a sticker that is in a visible location on the fixture or appliance. Tap make & model is usually visible on the tap itself. More here: https://goo.gl/cqQVi8

How may SINGLE FLUSH toilets?		How many DUAL FLUSH toilets?		OTHER / COMPOST / BIDET / URINAL? CIRCLE
Number with Small Cistern:	Number with Large Cistern:	Number with Small Cistern:	Number with Large Cistern:	Detail:
WELS rating:	Flush volume (if known):	WELS rating:	Flush volume (if known):	

b: Please tell us about the SHOWER(S) in your home using the boxes provided below:

LOW FLOW Shower Head:		NORMAL Shower Head:		OTHER / WATERFALL / UNSURE: CIRCLE	
WELS rating:	How many shower fittings?	WELS rating:	How many shower fittings?	WELS rating:	How many shower fittings?
Showers per week:	Average time in shower:	Showers per week:	Average time in shower:	Showers per week:	Average time in shower:

c: Please tell us about the BATHS / SPAS in your home using the boxes provided below:

Normal Bath:	How many in the home?	Spa Bath / Spa Pool:	How many on the property?	Other:	How many on the property?
Fills per week:	How full (e.g. ½ full)?	Fills per week:	Volume or Dimensions:	Detail:	

d: Please tell us about the HAND BASINS in your home using the boxes provided below:

Mixer / Joined Taps:	How many hand basins?	Separate Hot & Cold:	How many hand basins?	Other:	How many hand basins?
Tap make & model:	WELS rating:	Tap make & model:	WELS rating:	Detail:	

Any further notes on your bathroom:..
....
....
....
....
....
....
....

Q3: LAUNDRY Water Use:

a: How many LAUNDRY TUBS are in your home?.................... How often are they used? ....

b: Please tell us about the WASHING MACHINE(S) in your home using the boxes provided:

WELS ratings are listed on a sticker that is in a visible location on the appliance. The make and model information is on a label on the back-side of the machine console.

Front Loader:	How many front loaders?	Top Loader:	How many top loaders?	Off-Site Washing:
Loads per week:	Make & Model:	Loads per week:	Make & Model:	Details:
Temperature Settings: HOT / WARM / COLD	Size:	Temperature settings: HOT / WARM / COLD	Size:	
WELS rating:	Age of machine:	WELS rating:	Age of machine:	

Any further notes on your laundry: ....

....

....

Q4: HOT WATER SYSTEM Details:

a: Please tell us about the hot water system(s) in your home using the boxes provided below:

Information about your hot water system can generally be found as a label on the indoor cylinder or outdoor gas unit.

1	Primary system? YES / NO	Type of System (see examples below):	Circle: Mains Pressure / Low Pressure	Circle: Pressure Reducing Valve / Header Tank	Size of System (Litres):
2	Primary system? YES / NO	Type of System (see examples below):	Circle: Mains Pressure / Low Pressure	Circle: Pressure Reducing Valve / Header Tank	Size of System (Litres):
3	Primary system? YES / NO	Type of System (see examples below):	Circle: Mains Pressure / Low Pressure	Circle: Pressure Reducing Valve / Header Tank	Size of System (Litres):

Type of System Examples: *Electric Cylinder*, *Gas Cylinder*, *Instant Electric*, *Instant Gas*, *Electric & Wetback*, *Gas & Wetback*, *Electric & Solar*, *Solid Fuel Cylinder*, *Electric, Solar & Wetback*, *Night Rate Electric*, *Zip Heater*, *Heat Pump (i.e Quantum)*

Any further notes on your hot water system: ....

....

....

b: How often do you run out of HOT water? (circle relevant answer below)

Never	Rarely	Sometimes	Often

Q5: KITCHEN Water Use:

a: How many kitchen sinks are in your home? .... **Tap Configuration:** Mixer / Separate

b: Please tell us about the DISHWASHER(S) in your home using the boxes provided below:
The make and model information is generally found in a label on side of the dishwasher door or drawer.

Number of dishwashers:	Make & Model of dishwasher:	Loads per week:	Usual Settings (i.e. economy, hot, fast, etc.):

c: Please tell us about any OTHER water using appliances in your kitchen using the boxes provided below:

Waste Disposal:	How many disposal units?	Other:	Other:
Details:		Detail:	Detail:

Any further notes on your kitchen: ....
....
....
....

Q6: OUTDOOR WATER USE:

a: How many EXTERNAL TAPS are on your property? ....

b: Do you have a SPRINKLER SYSTEM (automated)? .... **(non-automated)?** ....

c: How often do you WATER THE GARDEN (hand)? .... **(sprinkler system)?** ....

d: How often do you WASH THE CAR (hose)? .... **(bucket)?** ....

e: Do you have a RAIN TANK or RAIN DRUM? .... **What is the volume?** ....

What is the rainwater used for? (e.g. Garden Irrigation, Toilet Flushing, Washing Machine, Other) ....
....
....

f: Do you have a GREYWATER SYSTEM? .... **What is the volume?** ....

A greywater system collects water used in hand basins, laundry and/or showers, for re-use in toilets and/or garden irrigation. For more information, refer www.level.org.nz/water

What sources does the greywater come from? (e.g. Kitchen, Shower, Laundry, Other) ....

....

....

What is the greywater used for? (e.g. Garden Irrigation, Toilet Flushing, Other) ....

....

....

g: Do you have a SWIMMING POOL? .... **What is the volume?** .... **How often is it filled?** ....

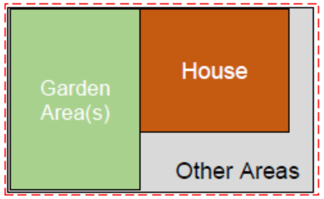
h: Do you have an OUTDOOR SPA? .... **What is the volume?** .... **How often is it filled?** ....

i: What is the approx. area of your HOUSE? (brown area) .... m^2

j: How many BEDROOMS are in your home? ....

k: What is the approx. area of your SECTION? (total inside red dotted line) .... m^2

l: What is the approx. area of your GARDEN (e.g. lawn, flowers)? (green area) .... m^2



Any further notes on your outdoor water use: .... If yes, provide details:

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Q7: HOUSEHOLD OCCUPANCY Details:

a: Please tell us about the PEOPLE you live with: (insert yourself in the first blank row)

Name	Gender	Age	Ethnicity	Relationship to You	Employment	Occupation	Qualification	Home Occupancy
John	M	55	NZ Pakeha	-	Retired / Self-Employed	Building / Law	NZ Trade Cert	Morning/Day/Evening

b: Do you OWN THIS HOUSE?

- ☐ Own house freehold.
- ☐ Own house, but with a mortgage.
- ☐ Rent or lease this house.
- ☐ Other (please state): ....

c: What DATE / year did you move into this house? ....

d: How many occupants regularly CONTRIBUTE to the INCOME of the household? ....

e: What is the APPROXIMATE TOTAL INCOME of this household? (circle relevant answer below)

<$20,000	$20,001 - $40,000	$40,001 - $60,000	$60,001 - $80,000	$80,001 - $100,000	$100,001 - $120,000	$120,001 - $140,000	$140,001 - $160,000	$160,001 - $180,000	$180,001 - $200,000	>$200,000

The information provided on this page will be used for statistical purposes only.

Q8: ANY FURTHER COMMENTS? ....

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- - PLEASE NOTIFY US IF ANYTHING REPORTED IN THIS QUESTIONNAIRE CHANGES DURING THE MONITORING PERIOD - -

-- THANK YOU FOR YOUR TIME AND EFFORT IN COMPLETING THIS FORM --

Please email to water@branz.co.nz or mail to LEB Water, BRANZ, Private Bag 50 908, Porirua 5240. Please visit www.branz.co.nz/water for updates and more information on the study.