SEQ Residential Water End Use Study: Validation Trial of CSIRO End Use Sensor

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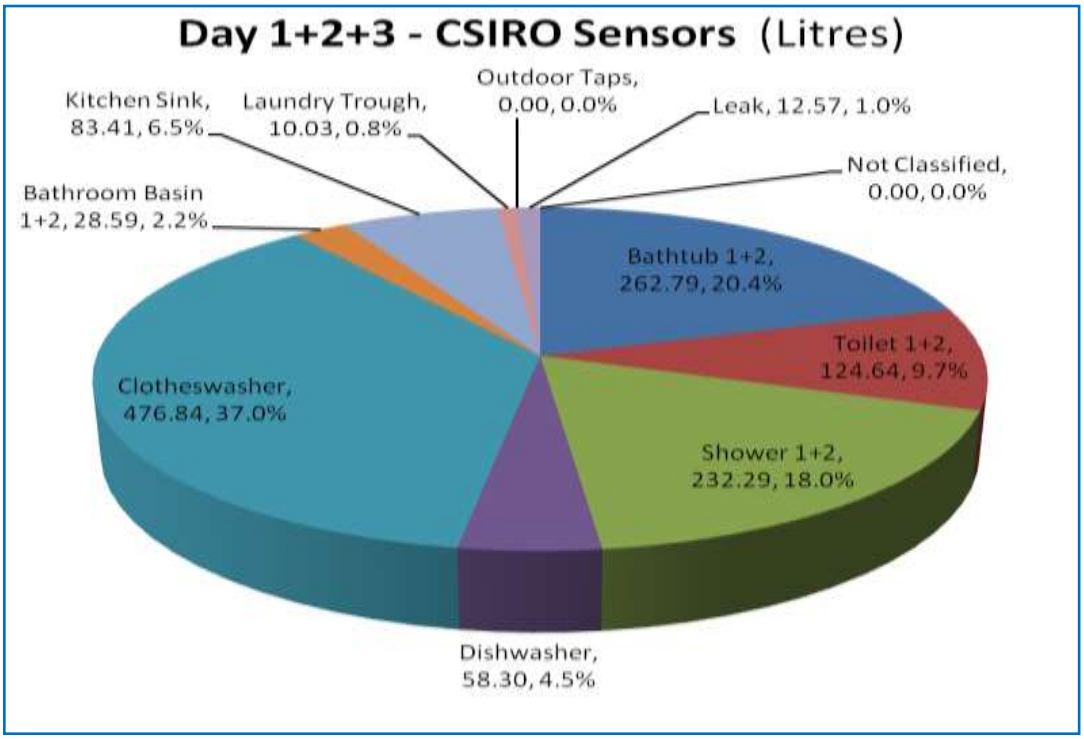
September 2012



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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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Cover Photograph:

Description: Figure showing end use measurements with CSIRO sensor

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This research was undertaken as part of the South East Queensland Urban Water Security Research Alliance, a scientific collaboration between the Queensland Government, CSIRO, The University of Queensland and Griffith University.

Particular thanks go to Rodney Stewart and his team from Griffith University for their cooperation and assistance, and his wife Lisa for allowing us to use the family home to test the end use sensors, and for keeping the water use diary.

FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

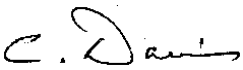
As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.



Chris Davis
Chair, Urban Water Security Research Alliance

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

A prototype CSIRO end use sensor system was trialled in one house in South East Queensland as part of the SEQREUS trial. The results of the field trial demonstrated conclusively that the CSIRO system can accurately determine end use at the individual tap level, and results were superior to those obtained using Trace Wizard© software. The CSIRO system is a practical alternative to a manual householder diary without its vulnerability to human error, and it places much less burden on participating homeowners.

Some minor issues were noted due to a hardware timing error that resulted in occasional mismatching of the kitchen, laundry and bathroom manual tap data. The sensors have subsequently been modified to prevent a recurrence of this problem. The other issue was infrequent loss of communications from the WiFi network or the 3G modem. The prototype sensors did not have on-board data memory so this meant that there were gaps in the data. However, the next version of the end use sensors will have on-board memory, so that any temporary interruption to communications will not result in data loss.

It is intended to further develop the system in conjunction with a commercial partner. Once this is done, end use measurement will become a routine operation for water utilities, which should greatly assist them to better manage urban water systems in the face of continuing growth and climate uncertainty.

1. INTRODUCTION

Australian water utilities rely on estimates of residential end use to help plan for urban growth, evaluate the effectiveness of water saving technologies and secure our future water supplies. At present, end use measurements usually rely on commercial Trace Wizard© software, which uses proprietary pattern matching algorithms to categorise flow measurements from the water meter. This data must then be further evaluated by trained personnel to give an estimate of end use. This is a labour-intensive exercise, and only gives approximate results, as many water end usage patterns cannot be reliably distinguished, particularly for manually operated taps (e.g. laundry, hand basin or kitchen sink) and overlapping events. To improve accuracy, these results are often correlated with a householder water use diary, in which case data reliability is still somewhat erratic as it depends on 100% user compliance.

To address this issue, CSIRO are currently developing a prototype system that automatically and accurately determines residential water end use without the need for a householder diary. The prototype comprises sensors that associate acoustic responses from water use with flow from particular water outlets. When combined with volumetric flow data from a high resolution water meter, the system can accurately assign water flow to each tap outlet without requiring analysis by trained operators.

A South East Queensland (SEQ) Residential End Use Study (SEQREUS) has been undertaken by a team led by Assoc Prof Rodney Stewart from the Smart Water Research Centre at Griffith University for the past three years, funded by the Urban Water Security Research Alliance (the Alliance). That project aims to remotely collect and analyse residential end use data using Trace Wizard© for a sample of 320 households located within four local government areas (Ipswich, Brisbane, Gold Coast, and Sunshine Coast).

Following discussions with Assoc Prof Stewart and Don Begbie, Director of the Alliance, it was agreed that this would be an ideal opportunity to validate the performance of the CSIRO end use sensor prototype. It was agreed that the CSIRO prototype sensor would be installed in one home, on the Gold Coast in SEQ, as a sub-project to compare results with a Trace Wizard© end use trial, as part of an extension to the SEQREUS project.

Consequently, a trial was undertaken in which three different estimates of end use were obtained simultaneously using Trace Wizard©, a householder diary, and from the CSIRO acoustic sensor data.

The CSIRO end use system uses responses from the acoustic sensors that coincide with flow events from the high resolution water meter to assign end use. The acoustic sensors add two extra dimensions to the end use analysis – spatial identification allows the water flow to be assigned to a particular water zone (e.g. kitchen, bathroom), while the acoustic characteristics can be matched to a particular water outlet. At present, this evaluation is done manually, but it is readily amenable to automation.

2. END USE SENSOR PROTOTYPE

The CSIRO end use sensor prototype was developed by CSIRO at its Clayton laboratories in Melbourne. The prototype comprises mains powered sensor modules that communicate via an inbuilt WiFi link (Figure 1). They also have a USB cable that can be directly connected to a PC. There are two types of sensor modules in the basic version (Figure 2): an acoustic sensor to record the sound associated with particular water outlets; and a water volume sensor attached to the utility water meter at the property supply point. To enable estimates of hot and cold water use from individual taps, a temperature sensor was also fitted to the hot water service outlet to indicate hot water use.

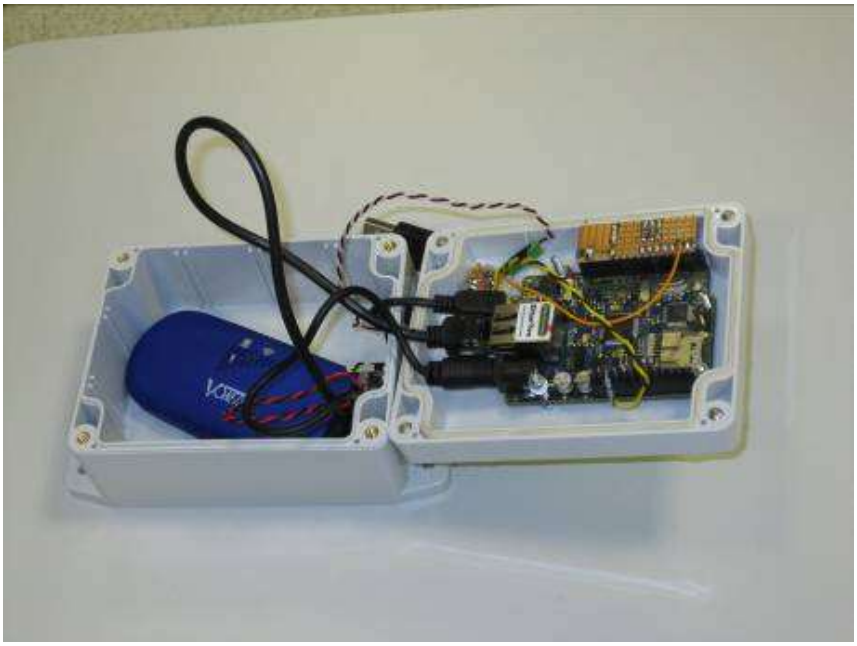


Figure 1: Internals of typical sensor module showing WiFi link (blue item to left).

Figure 2: End use sensor modules for SEQ validation trial.

3. END USE SENSOR PROTOTYPE INSTALLATION

The end use sensors were installed at the field trial site on the Gold Coast on 1-3 May 2012. The attached floor plan of the house shows the location of the various sensor modules (Figure 3). Acoustic sensors were placed in the kitchen, laundry, bathroom and ensuite; a water volume sensor was attached to the high resolution water meter from the Trace Wizard© trial, and a temperature sensor module was attached to the hot water service (HWS) outlet to indicate hot water flow. Each of the sensor modules relayed data in real time to a 3G wireless modem located in the study, which then transferred the data to an external server for subsequent retrieval and analysis.

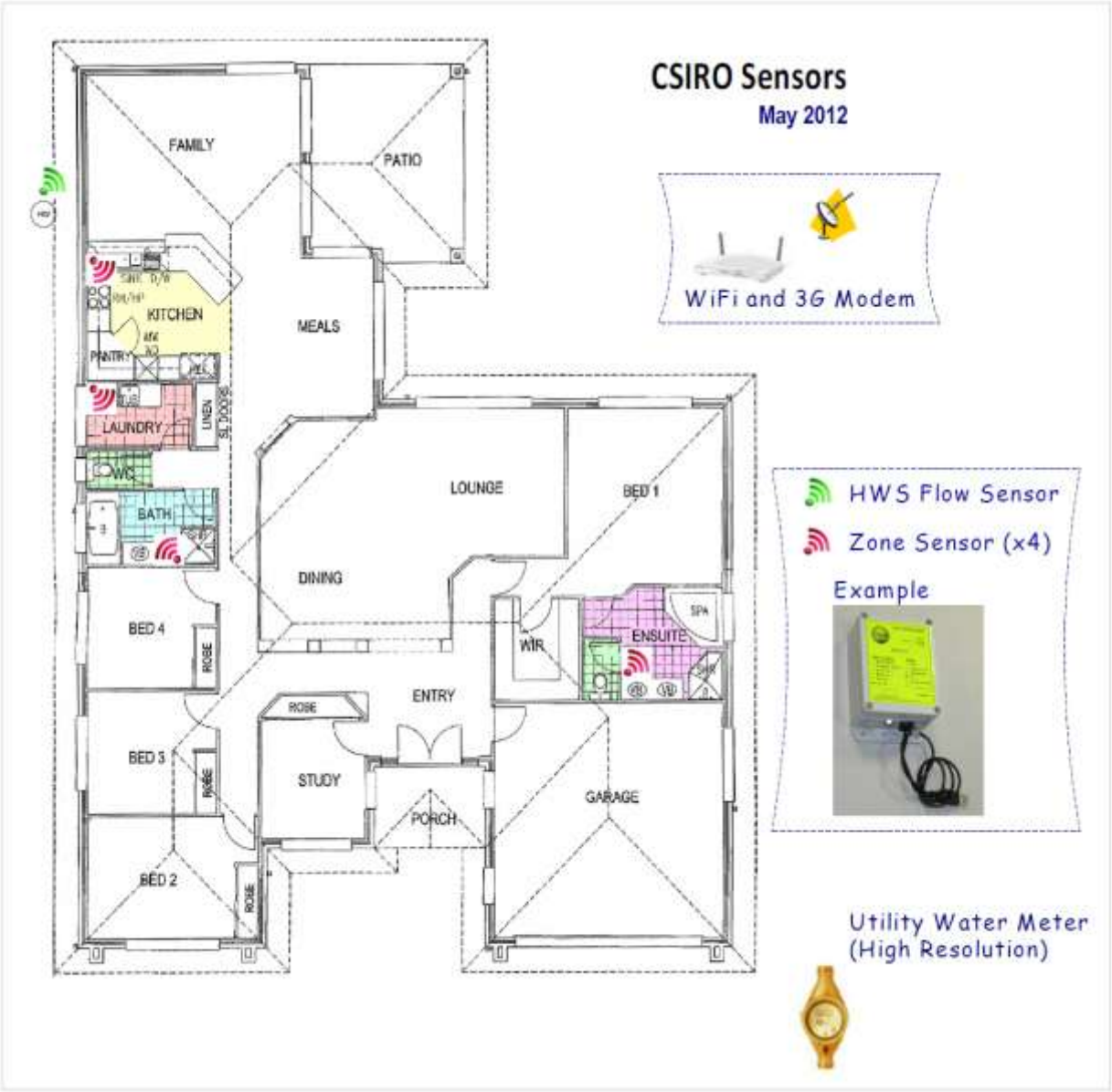


Figure 3: Floor plan of field trial house on the Gold Coast showing location of end use sensors.

Details of the locations and outlets monitored by these 3 types of sensors are as follows:

1. One acoustic sensor in each wet zone to identify water flow from local outlets:
    a. Kitchen – sink mixer tap (hot/cold), dishwasher (cold).
    b. Laundry – tub (hot/cold), clothes washer (hot/cold).
    c. Bathroom – bath (hot/cold), hand basin (hot/cold), shower (hot/cold), toilet (cold).
    d. Ensuite – shower (hot/cold), toilet (cold), spa (cold).
2. Temperature sensor:
    a. Hot water service outlet (HWS).
3. Interface to high resolution water meter at the front of the property (from Trace Wizard© study).

Typical installations are shown in Figure 4, 5 and Figure 6.

Figure 4: Acoustic sensor in ensuite.

Figure 5: Acoustic sensor in kitchen.

Figure 6: External utility water meter with cable connecting to CSIRO sensor module.

3.1. Commissioning

Following installation, the end use system was monitored remotely for one week to ensure that the sensors and WiFi modules were functioning correctly. After this commissioning period, we continued monitoring the CSIRO end use sensor data for a further four weeks until 9 June 2012. On three separate days during this period, a Trace Wizard© study was undertaken to enable comparison with the CSIRO sensor results.

4. END USE VALIDATION TRIAL

The Trace Wizard© reference study including logging water use data to the householder diary was undertaken on Wed 16 May, Fri 25 May and Fri 8 June by Griffith University researchers. A comparison of the daily end use results from Trace Wizard©, the householder diary and the CSIRO sensors is set out on the following pages.

The water outlets were grouped into 4 categories:

A: Automated solenoid operated water valves with reproducible flow characteristics (dishwasher/clothes washer/ toilet);

M1: Manually operated water outlet with reasonably predictable flow characteristics (bath/shower);

M2: Manual outlet, but with highly variable hard to characterise flow characteristics (other taps); and

Other: Leaks, unrecorded events.

4.1. Day 1 (16 May 2012)

The results in Table 1 show the performance of each end use approach. The 'actual' value was assigned after carefully examining all the data and using expert judgement to determine the most likely result. End use results that exactly match the actual assigned value are highlighted in green. Whilst the CSIRO sensors measure end use at the tap level, for comparative purposes the toilet, bathtub, shower and basin results have been aggregated.

Table 1: Day 1 end use comparing results from Trace Wizard©, Householder Diary and CSIRO sensors.

CATEGORY	Type	Trace Wizard© (L)	Diary (L)	CSIRO (L)	Actual (L)
Dishwasher	A	16.54	16.54	16.54	16.54
Clothes washer	A	92.07	92.07	92.07	92.07
Toilet 1+2	A	16.09	17.61	22.91	22.91
A1 Total		*124.70*	*126.22*	*131.52*	*131.52*
Bathtub 1+2	M1	57.85	57.85	57.85	57.85
Shower 1+2	M1	69.91	64.22	64.22	64.22
A2 Total		*127.76*	*122.07*	*122.07*	*122.07*
Basin 1+2	M2	NA	1.16	1.16	1.16
Kitchen Sink	M2	NA	41.76	41.19	44.95
Laundry Trough	M2	NA	0.00	4.70	0.94
Outdoor Taps	M2	NA	0.00	0.00	0.00
Manual Tap Total		*48.22*	*42.92*	*47.05*	*47.05*
Leak	Other	0.01	0.00	0.05	0.05
Not Classified	Other	NA	9.48	0.00	0.00
TOTAL:		**300.69**	**300.69**	**300.69**	**300.69**

Misclassified Events – Day 1

Trace Wizard© misclassified a simultaneous event when it did not identify a toilet flush that occurred during a shower, and therefore overestimated shower water use and underestimated toilet end use.

The Householder Diary missed two toilet flushes and one use of the kitchen sink tap.

The CSIRO sensors mistakenly assigned one use of the kitchen tap to the laundry. Apart from that, the CSIRO sensors matched the actual end use predictions.

Pie charts comparing end use results from Trace Wizard© and CSIRO sensors are shown in Figure 7.

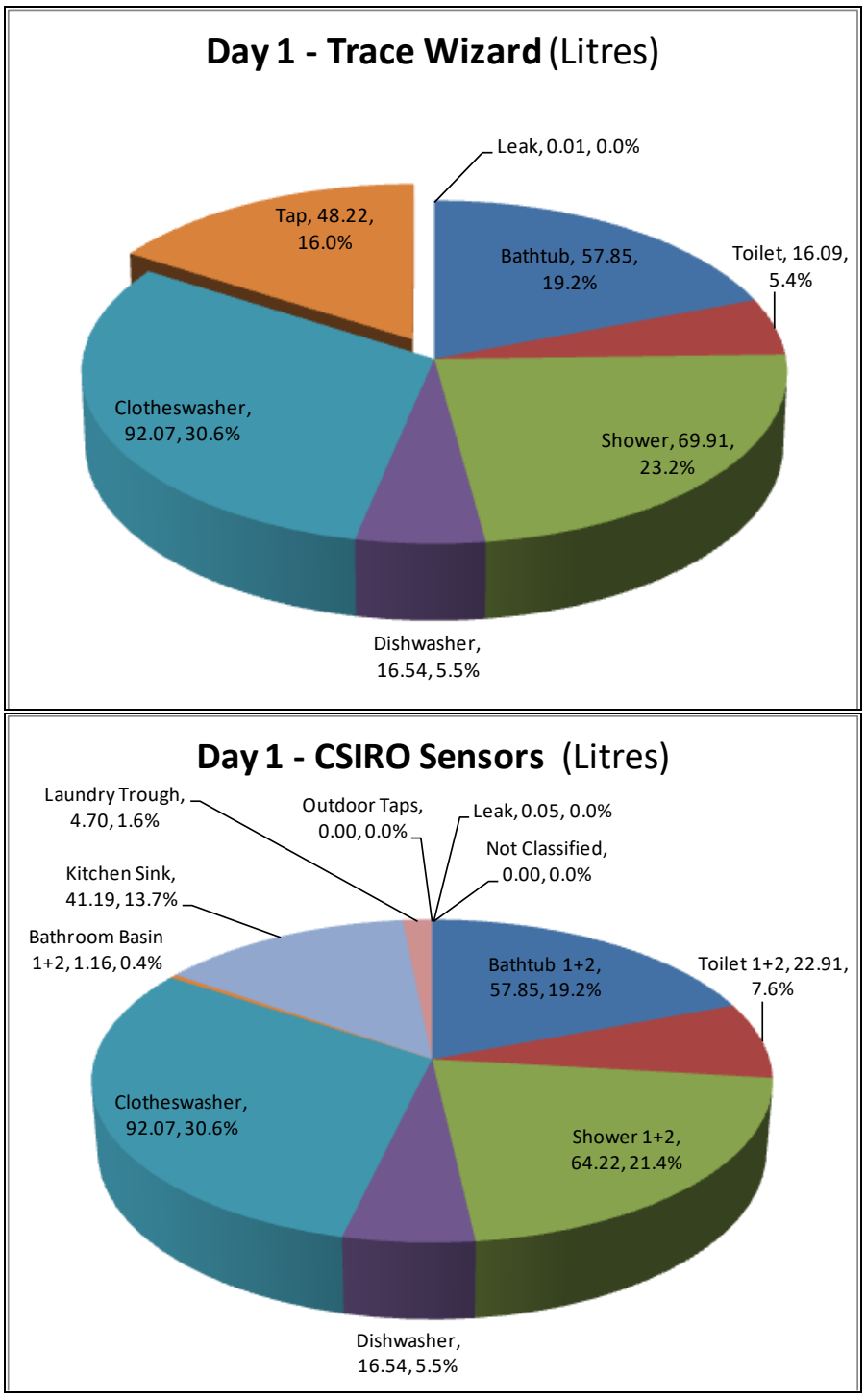


Figure 7: Pie charts from Day 1 comparing end use results from Trace Wizard© (top) and CSIRO sensors (bottom).

4.2. Day 2 (25 May 2012)

The results in Table 2 again demonstrate the performance of each end use approach. End use results highlighted green exactly matched the 'actual' value.

Table 2: Day 2 end use comparing results from Trace Wizard©, Householder Diary and CSIRO sensors.

CATEGORY	Type	Trace Wizard© (L)	Diary (L)	CSIRO (L)	Actual (L)
Dishwasher	A1	15.68	15.68	15.68	15.68
Clothes washer	A1	81.66	83.04	83.04	83.04
Toilet 1+2	A1	48.05	56.92	56.92	56.92
A1 Total		*145.39*	*155.64*	*155.64*	*155.64*
Bathtub 1+2	A2	204.94	204.94	204.94	204.94
Shower 1+2	A2	90.62	90.62	90.62	90.62
A2 Total		*295.56*	*295.56*	*295.56*	*295.56*
Basin 1+2	Manual	NA	4.18	4.99	4.18
Kitchen Sink	Manual	NA	29.46	28.75	29.56
Laundry Trough	Manual	NA	0.00	0.00	0.00
Outdoor Taps	Manual	NA	0.00	0.00	0.00
Manual Tap Total		*44.09*	*33.74*	*33.74*	*33.74*
Leak	Other	7.98	0.00	8.08	8.08
Not Classified	Other	NA	8.18	0.00	0.00
TOTAL:		**493.02**	**493.02**	**493.02**	**493.02**

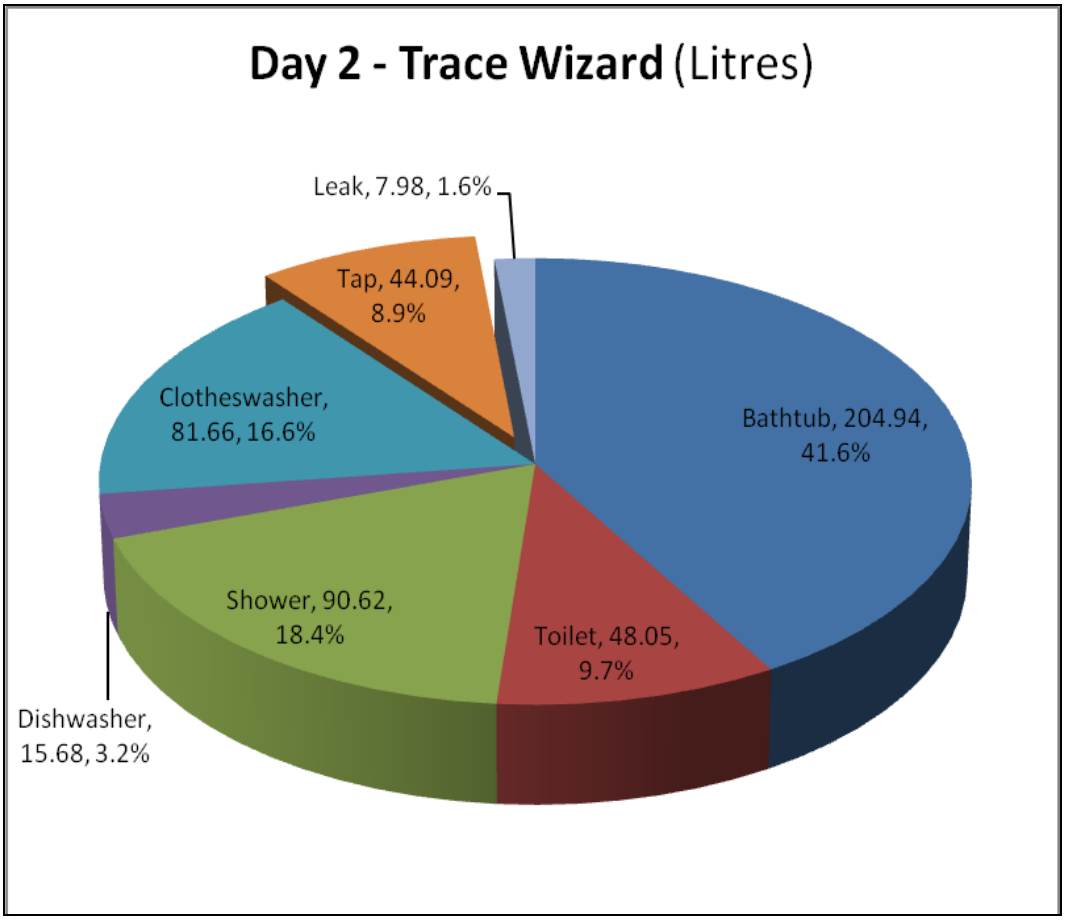
Misclassified Events – Day 2

Trace Wizard© missed a toilet flush and slightly under-estimated flow from the clothes washer, consequently slightly over-estimating tap water use. These under-estimations are due to the nature of the fingerprint algorithms used in the software.

The Householder Diary accurately recorded all water uses except for one small water event from the kitchen sink (0.01 L).

The CSIRO sensors mistakenly assigned one use of the kitchen tap to the bathroom basin. Apart from that, the CSIRO sensors matched the actual end use predictions.

Pie charts comparing end use results from Trace Wizard© and the CSIRO sensors are shown in Figure 8.



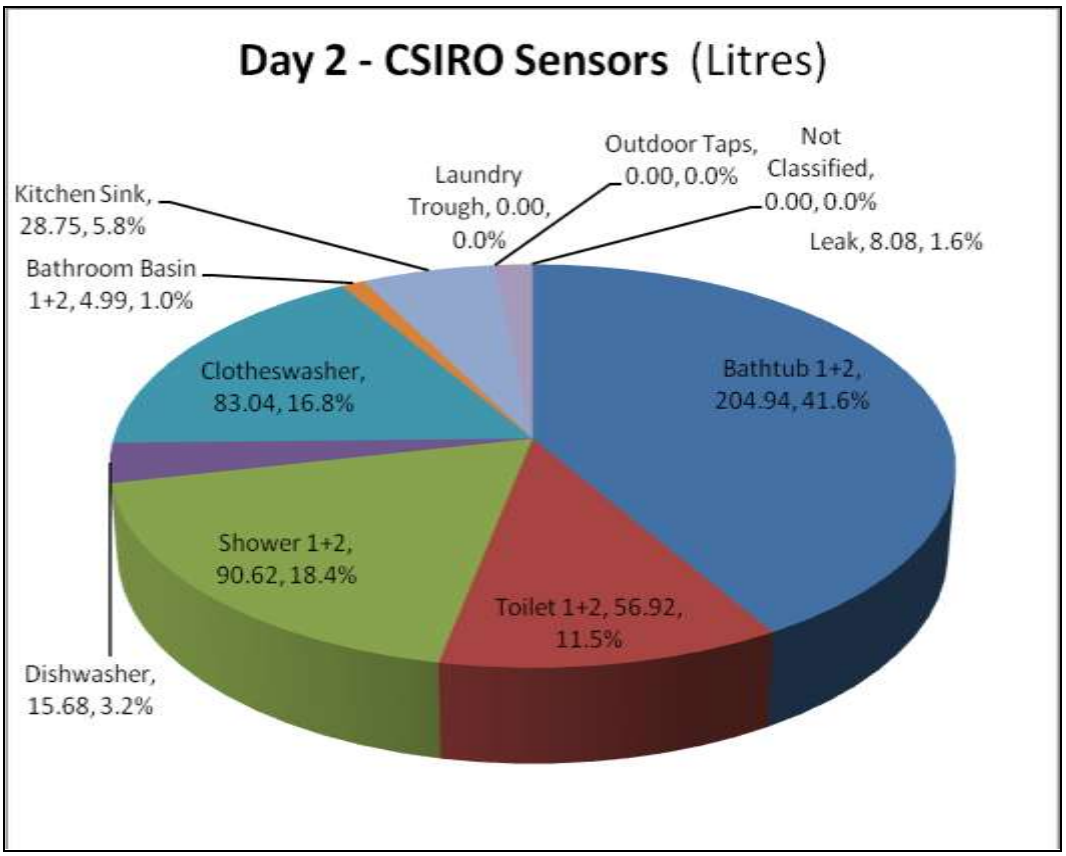


Figure 8: Pie charts from Day 2 comparing end use results from Trace Wizard© (top) and CSIRO sensors (bottom).

4.3. Day 3 (8 June 2012)

The results in Table 3 demonstrate the performance of each end use approach. End use results highlighted green exactly match the 'actual' value.

Table 3: Day 3 end use comparing results from Trace Wizard©, Householder Diary and CSIRO sensors.

CATEGORY	Type	Trace Wizard (L)	Diary (L)	CSIRO (L)	Actual (L)
Dishwasher	A1	58.01	47.23	58.30	58.30
Clothes washer	A1	486.15	476.84	476.84	476.84
Toilet 1+2	A1	108.76	119.34	124.64	124.64
A1 Total		*652.92*	*643.41*	*659.78*	*659.78*
Bathtub 1+2	A2	262.79	262.79	262.79	262.79
Shower 1+2	A2	237.98	232.29	232.29	232.29
A2 Total		*500.77*	*495.08*	*495.08*	*495.08*
Basin 1+2	Manual	NA	22.44	22.44	22.44
Kitchen Sink	Manual	NA	10.41	13.47	15.01
Laundry Trough	Manual	NA	3.79	5.33	3.79
Outdoor Taps	Manual	NA	0.00	0.00	0.00
Manual tap total		*31.03*	*41.24*	*41.24*	*41.24*
Leak	Other	4.44	0.00	4.44	4.44
Not Classified	Other	0.00	20.11	0.00	0.00
TOTAL:		**495.75**	**495.75**	**495.75**	**495.75**

Misclassified Events – Day 3

For Day 3, Trace Wizard© analysis was found to slightly under-estimate the flow from the dishwasher and toilets, and over-estimate flow at the clothes washer.

Comparing the Diary with the water meter, it was found that some events were not recorded – one use of the dishwasher was overlooked, as was one use of the kitchen sink tap.

The CSIRO sensors again mistakenly assigned one use of the kitchen tap to the laundry. Apart from that, the CSIRO sensors matched the actual end use predictions.

Pie charts comparing end use results from Trace Wizard© and the CSIRO sensors are shown in Figure 9.

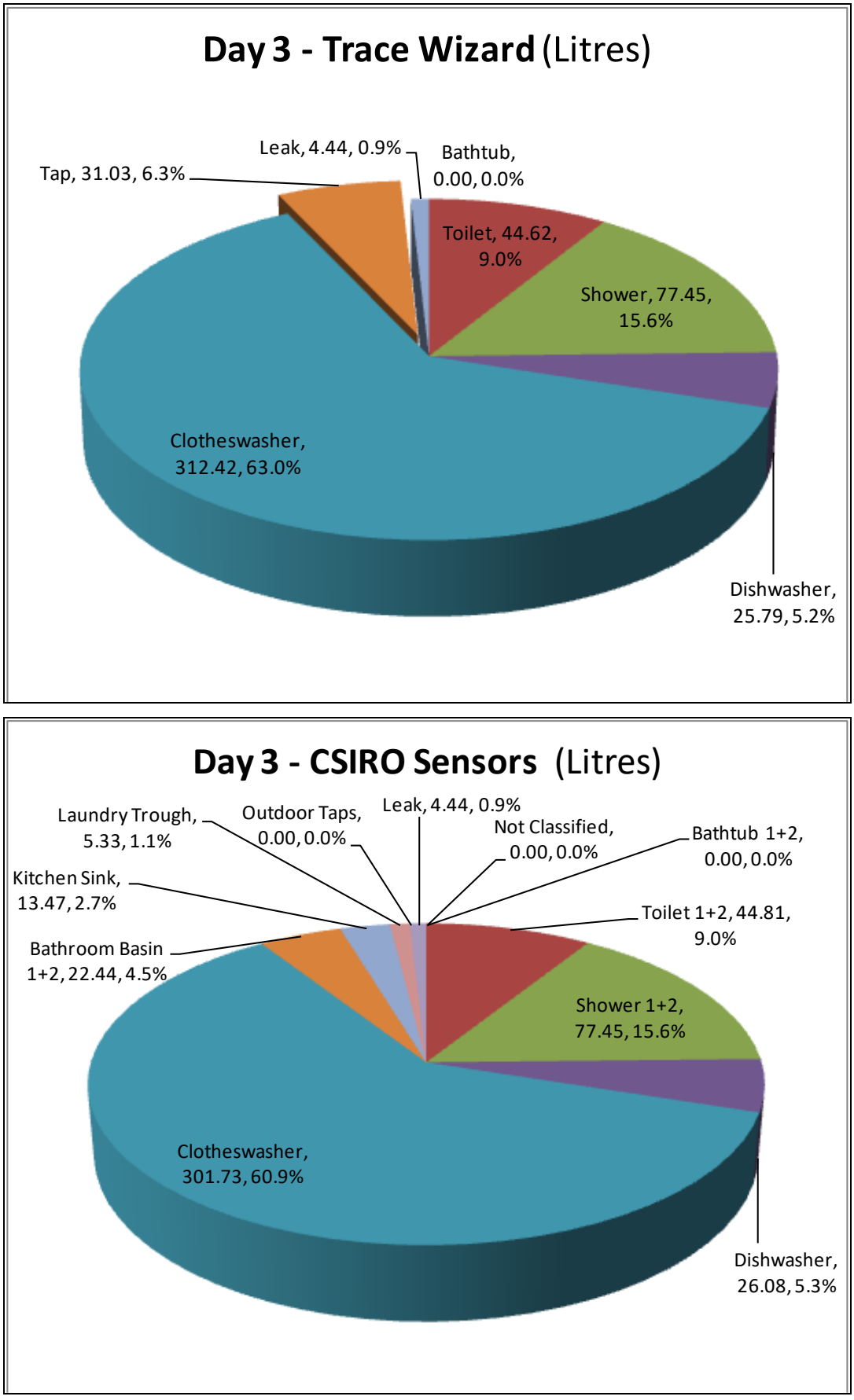


Figure 9: Pie charts from Day 3 comparing end use results from Trace Wizard© (top) and CSIRO sensors (bottom).

4.4. Overall Results Days 1 – 3 (16 May, 25 May, 8 June 2012)

An overall assessment of the end usage results is given in Table 4. Pie charts of the end use predictions for the three methods tested and the actual results are also shown in Figure 10.

The CSIRO sensors were the only method to match exactly the actual end use results for categories A1 and A2, and to correctly predict total manual tap end use (Table 4). However, the CSIRO sensors had an occasional error in discriminating manual tap end use between the laundry trough, kitchen sink and bathroom basin. This was subsequently found to be due to a clock error in the acoustic sensor modules, so that the time of the acoustic signal did not always match the time of the flow event from the water meter. The modules have since been modified to prevent a recurrence of this timing error.

Table 4: Day 1+2+3 end use comparing results from Trace Wizard©, Householder Diary and CSIRO sensors.

CATEGORY	Type	Trace Wizard© (L)	Diary (L)	CSIRO (L)	Actual (L)
Dishwasher	A1	25.79	15.01	26.08	26.08
Clothes washer	A1	312.42	301.73	301.73	301.73
Toilet 1+2	A1	44.62	44.81	44.81	44.81
A1 Total		*382.83*	*361.55*	*372.62*	*372.62*
Bathtub 1+2	A2	262.79	262.79	262.79	262.79
Shower 1+2	A2	237.98	232.29	232.29	232.29
A2 Total		*500.77*	*495.08*	*495.08*	*495.08*
Basin 1+2	Manual	NA	27.78	28.59	27.78
Kitchen Sink	Manual	NA	81.63	83.41	89.52
Laundry Trough	Manual	NA	3.79	10.03	4.73
Outdoor Taps	Manual	NA	0.00	0.00	0.00
Manual tap total		*123.34*	*113.20*	*122.03*	*122.03*
Leak	Other	12.43	0.00	12.57	12.57
Not Classified	Other	0.00	37.77	0.00	0.00
TOTAL:		**1289.46**	**1289.46**	**1289.46**	**1289.46**

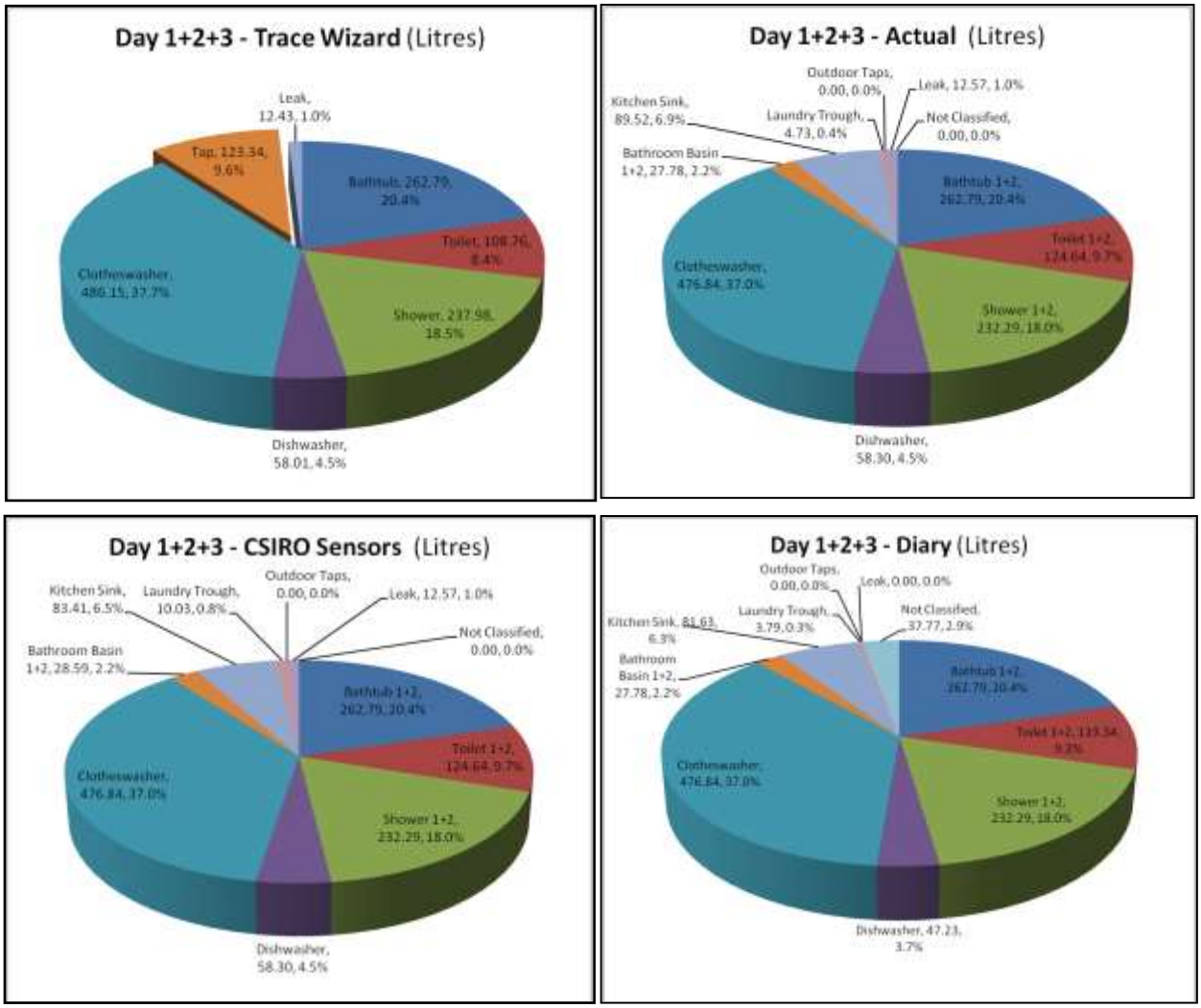


Figure 10: Pie charts comparing Trace Wizard©, CSIRO sensors, householder diary, and actual end use measurements.

4.5. Additional Information on Hot Water Usage

Along with the acoustic and flow sensors that provided the basic end use data, a temperature sensor was also installed on the hot water service outlet. This provided information about hot water flow to differentiate between cold water use and hot + cold use (Figure 11). The dishwasher, clothes washer, toilets and external taps used cold water only, whilst the other outlets used various amounts of hot water. Being winter, there was no use of the outdoor taps during the three-day trial. Proper measurement of hot water use would require a separate flow meter, but the temperature sensor still provided a good indication and was useful for confirming end use when evaluating the data, considering that some outlets use only cold water.

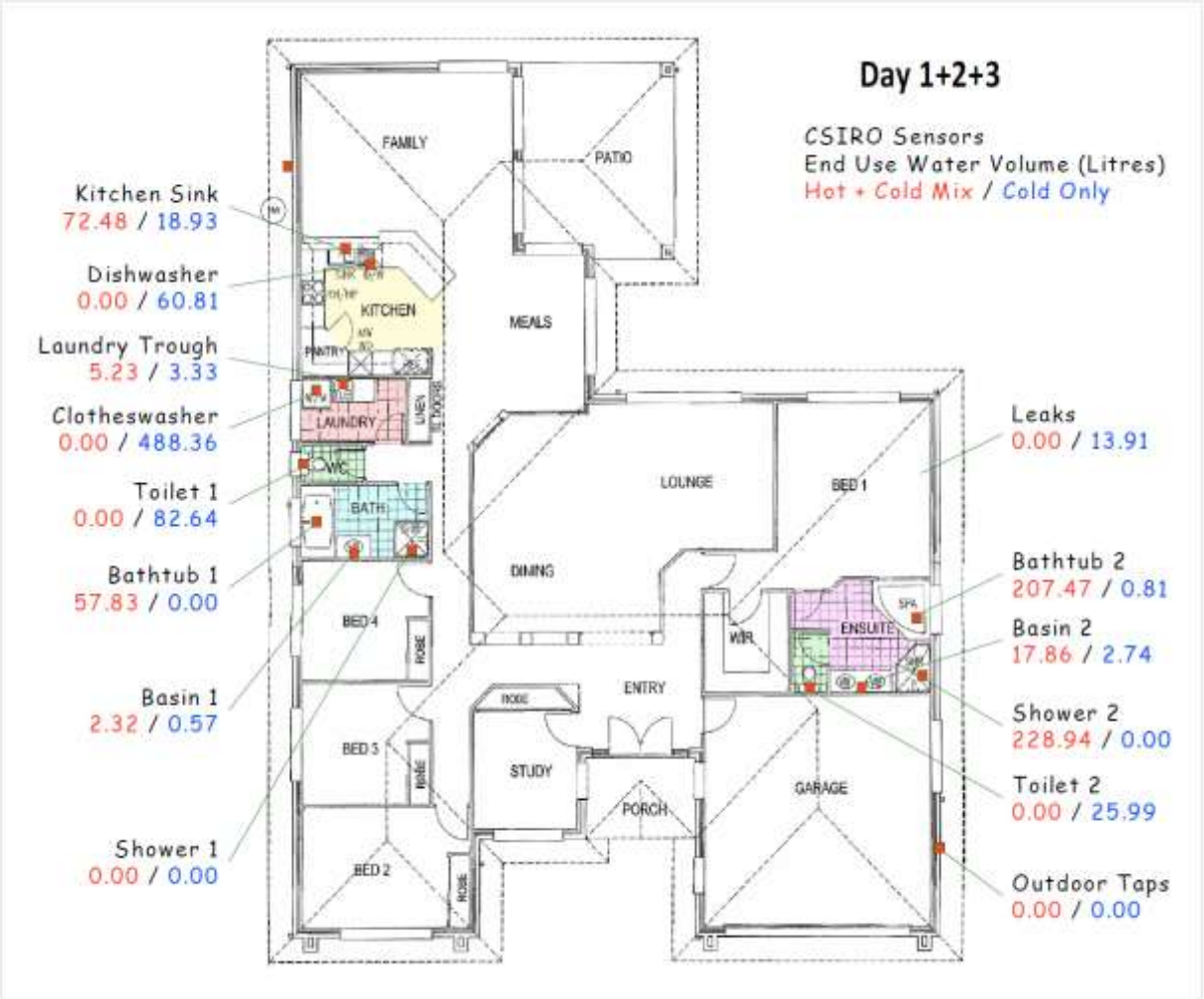


Figure 11: Floor plan of house showing relative amounts of cold vs. hot + cold water use.ater use.

5. CONCLUSIONS

The results of the field trial demonstrated conclusively that the CSIRO acoustic sensors can accurately determine end use when used in conjunction with flow data from a high resolution water meter. The results were superior to those obtained using Trace Wizard© software, and since the CSIRO sensors measure end use at the individual tap level, they also provide a practical alternative to a manual householder diary.

A couple of minor issues were noted with the CSIRO acoustic sensors. The first was due to a hardware timing error in the sensor modules, which resulted in occasional mismatching of the kitchen, laundry and bathroom manual tap data. The sensors have subsequently been modified to prevent a recurrence of this issue. The other issue was infrequent loss of communications from the WiFi network or the 3G modem. The prototype sensors did not have on board data memory so this meant that there were gaps in the data. However, the next version of the end use sensors will have on board memory so that data will not be lost.

The field trial showed that the CSIRO end use system could replace Trace Wizard© and householder diaries, and would therefore be much less of a burden on participating homeowners. The major step remaining is to automate the data interpretation step and find a commercial partner to manufacture the sensor system. Once this is done, end use measurement will become a routine operation for water utilities, which should greatly assist with managing urban water systems in the face of continuing population growth and climate uncertainty.