WATER QUALITY IN RAINWATER AND GREYWATER SYSTEMS: PRELIMINARY RESULTS

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ABSTRACT

As part of a larger commercial building feasibility study, the water quality in five rainwater harvesting and greywater recycling systems is being tested. This includes monthly and seasonal sampling from rainwater and greywater tanks, prior to treatment, to examine any transient contamination. This testing was initiated after respondents from the larger survey expressed concerns around water quality and health-related issues.

This sampling has, so far, found nil or low microbial loads for parameters measured (*E. coli*, *Campylobacter* spp., *Salmonella* spp., *Giardia* spp., *Cryptosporidium* spp. and culturable *Adenovirus*). Levels of *E. coli* of 2,400 MPN/100 mL were detected in one greywater sample, while the rainwater sampled from one of the buildings (C3) consistently contained *E. coli* in the range of 67–3,100 MPN/100 mL. All other microbial parameters were consistently negative. One sample of rainwater from another building (W1) had high levels of Zn, Fe, Ni and Pb. This variability of results is a typical characteristic of rainwater and greywater analysis. Overall, the measured parameters were generally within the expected ranges for rainwater and greywater.

A detailed health risk assessment will be carried out at the completion of sampling. However, the preliminary water quality results indicate suitability for non-potable use in commercial buildings and should not pose a risk to human health.

These perceived water quality and health issues may be an unfounded barrier, due to a lack of objective information. These preliminary results should help to alleviate this concern from the installation of more rainwater harvesting and greywater recycling systems in commercial buildings.

KEYWORDS

Rainwater, water quality, commercial buildings, greywater, microbial, health impact assessment

1 INTRODUCTION

A 3-year rainwater and greywater research programme aims to understand the operational and financial feasibility of rainwater harvesting and greywater recycling systems in New Zealand's commercial buildings. To do this, three research streams are used:

1. **Drivers and barriers**: identifies social and regulatory drivers and barriers to uptake of rainwater and greywater systems both perceived and actual.

2. **Building investigations**: assessment of case study buildings that have rainwater harvesting and/or greywater recycling systems currently in operation to understand operational and financial feasibilities.

3. **Network impacts**: estimates the effects of different uptake, climate and growth scenarios on the three water networks (potable water, stormwater and wastewater).

The content of this paper is two-fold. Firstly, it summarises the preliminary findings from an online survey undertaken in 2014 to understand the perceived social and regulatory drivers and barriers to the uptake of rainwater harvesting and greywater recycling systems in New Zealand. This is where the need for water quality testing is demonstrated, showing a real lack of awareness and education.

Secondly, the paper outlines the preliminary findings from testing water quality in five of the case study building investigations. This enables an understanding of the potential impacts on human health, being one of the primary concerns from respondents of the online survey.

In the context of this work, rainwater harvesting refers to the water captured via rainfall events on constructed surfaces, mostly from building roofs and façades. Greywater, on the other hand, refers to water used in and collected from wash hand basins and showers. This is then recycled and reused in toilets, urinals and sometimes irrigation.

2 PERCEPTIONS OF RAINWATER AND GREYWATER USE

To understand perceptions of rainwater harvesting and greywater recycling systems, an online survey was conducted as part of the drivers and barriers research stream. The survey sought responses on experiences, opinions and perceptions.

Although the overall study is specifically focused on commercial buildings, this research stream is inclusive of non-commercial buildings to gain a generalised and holistic view on New Zealanders' perceived drivers and barriers to uptake.

2.1 SURVEY METHOD

The survey was conducted using SurveyMonkey, an online surveying tool, and was open to anyone in New Zealand between July and November 2014. Therefore, the survey was a self-selected sample and perhaps provides the views of people more engaged in the industry or with a specific interest in rainwater harvesting and/or greywater recycling. The survey findings may therefore not always be accurately representative of the views of all New Zealanders.

The survey asked questions broadly around the following topics:

- Environmental and water awareness
- Importance of potable water
- Drivers and barriers
- Experience and perceptions of systems
- Products, technologies and expertise advancements
- Water supply networks
- General feedback.

Of this self-selected sample, 71 individuals responded. They were widely spread across a range of sectors, experiences and locations around New Zealand.

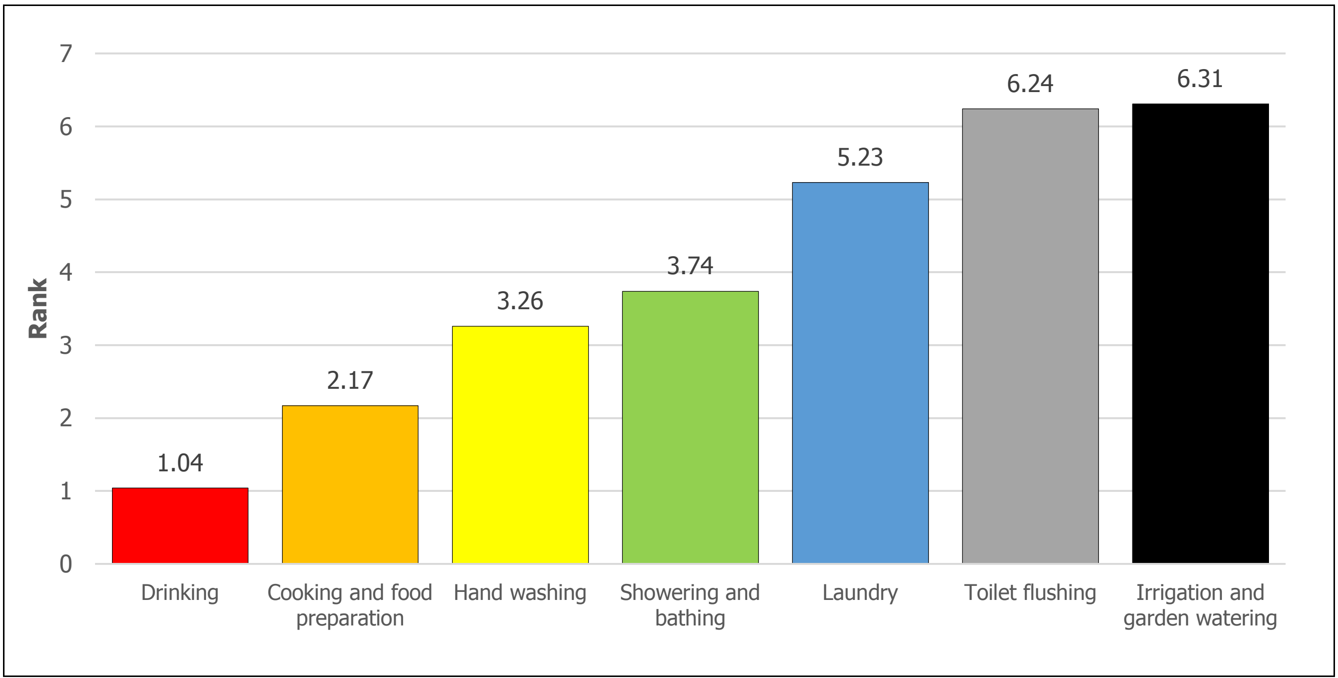
The environmental and water awareness questions were aligned with an existing nationwide survey on people's perceptions of the state of the New Zealand environment by Lincoln University (Hughey, et al., 2013). This was incorporated to better understand the awareness and educational levels of respondents in this survey in contrast to a more representative sample of the same population. The results showed a lower awareness of environmental issues in New Zealand than the Lincoln University survey but extremely similar perceptions on the state of the environment and water in New Zealand.

2.2 USE OF WATER, RAINWATER AND GREYWATER IN BUILDINGS

To get a gauge of water awareness, respondents were asked to rank water end uses in order of importance in terms of having treated, potable water supplied to end uses.

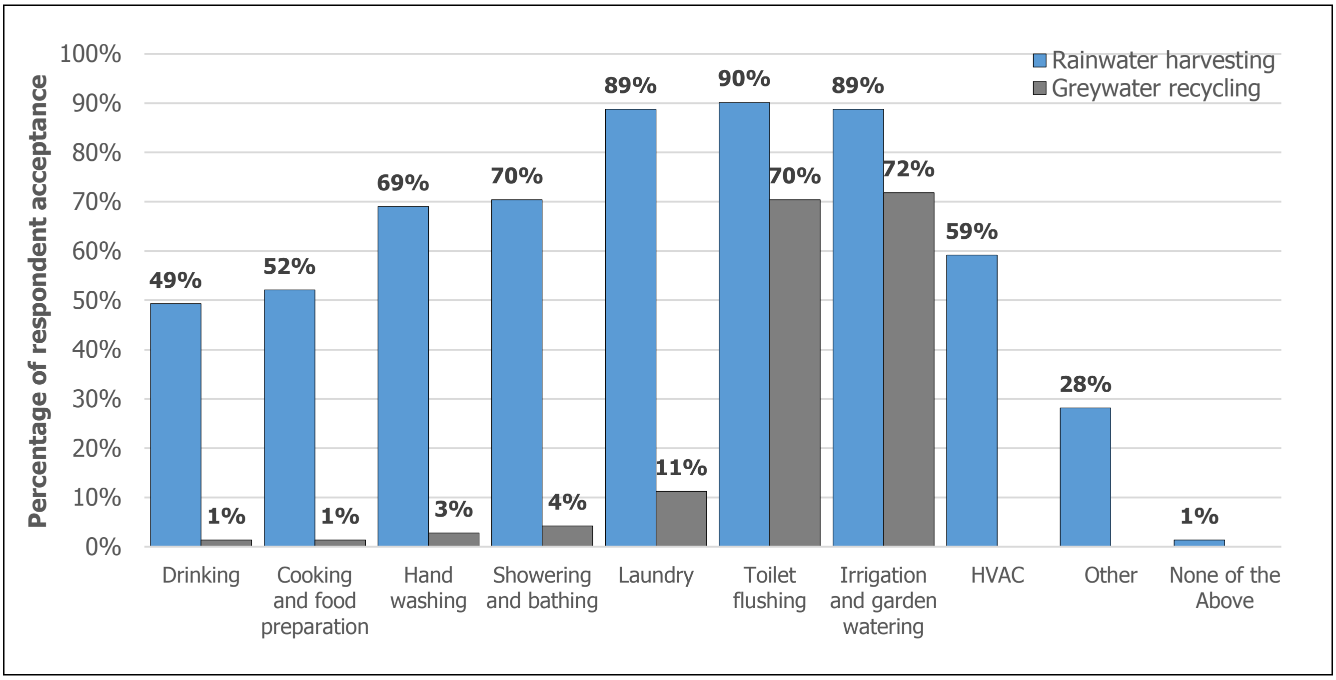
Figure 1 shows that the respondents are off to a good start! Drinking water and cooking and food preparation were perceived to be the most important, which are the two places of consumption. Toilet flushing and irrigation and garden watering were perceived to be the least important for which to have treated, potable water supply – two non-contact uses.

Figure 1: Perceived water quality importance (most important to least important).



If the treated potable water is replaced with rainwater, almost half (44%) of the respondents agree that the quality of rainwater is excellent in general, with even more indicating that rainwater is acceptable for drinking and cooking and food preparation. The results in Figure 2 also show that laundry, toilet flushing and irrigation are the most accepted uses for rainwater, which is strongly aligned to the treated, potable water scenario in Figure 1.

Figure 2: Perceived acceptable uses for rainwater and greywater.



Greywater is much clearer in terms of acceptability/unacceptability, despite some initial respondent confusion between the words 'rainwater' and 'greywater'. (There was much less understanding of greywater overall than that of rainwater, demonstrated through more respondents failing to answer greywater-centred questions.) Figure 2 shows (in grey) that greywater is perceived acceptable by almost three-quarters of respondents for toilet flushing and irrigation and garden watering. This also reinforces perceptions of both rainwater harvesting and treated potable water.

It should be noted that treatment and maintenance were purposely excluded from the survey to avoid complicating the results of overall perceptions. Of course, they need to be considered, and they have been thoroughly examined in the wider study.

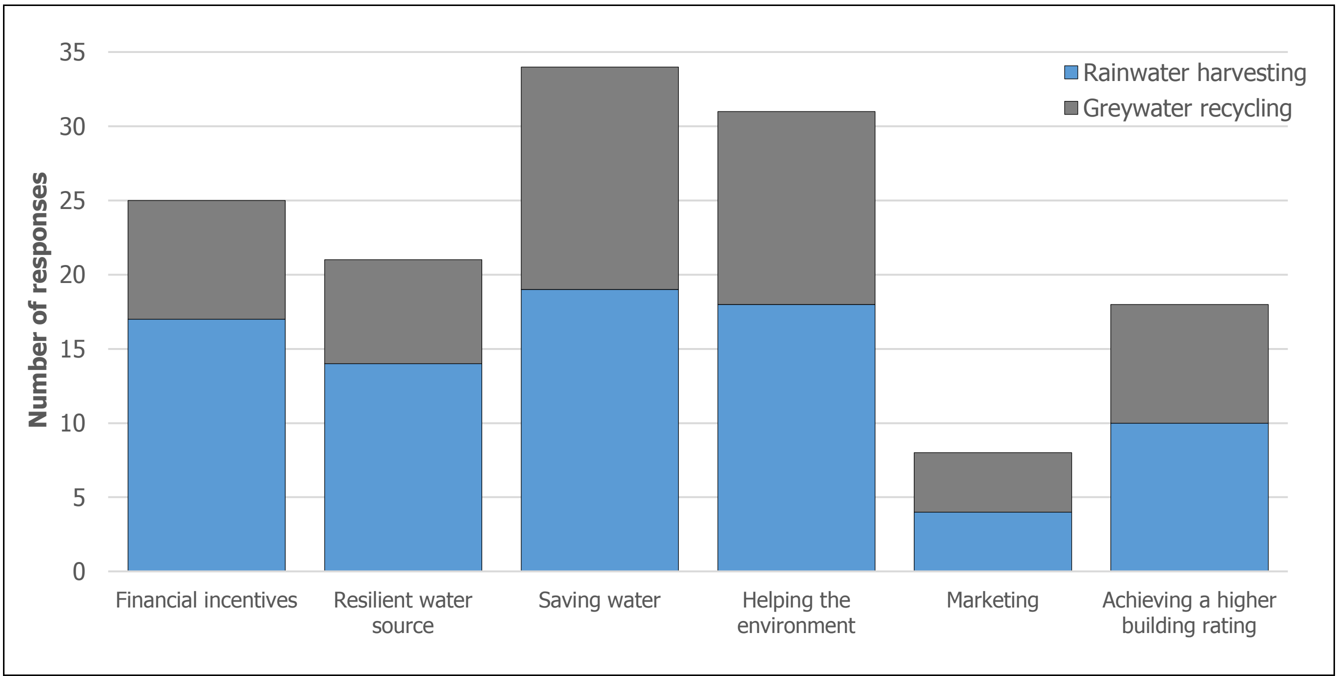
These results then raise the question if rainwater and greywater are largely accepted by the 71 respondents for non-potable and non-contact uses, why are these systems not seen more widely in New Zealand buildings?

2.3 PERCEIVED DRIVERS TO UPTAKE

Respondents were asked what the biggest incentives or drivers were: “What would make you consider installing a rainwater harvesting or greywater recycling system?”

As can be seen in Figure 3, the majority of respondents indicated that saving water was the greatest driver overall, followed closely by saving the environment. For greywater specifically, saving water and helping the environment were the biggest drivers.

Figure 3: Respondents' proposed reasons for uptake.



The use of rainwater and greywater for rental and sales marketability was rated rather low. Water is probably not yet valued enough to be an effective marketing mechanism.

When respondents were asked what the biggest incentives or drivers are for others in New Zealand, the top three categories listed for both rainwater harvesting and greywater recycling were:

- cost savings through reduction of water fees to the water supply network
- sustainability
- impact on supply, delayed infrastructure costs, reduced demand and reduced peaks.

A stakeholder survey undertaken by the Centre for Integrated Biowaste Research (CIBR) identified the five key drivers that (both positively and negatively) influence the use of recycled greywater in New Zealand (Cass & Beecroft, 2012) are:

- environmental conditions
- cost benefit of greywater recycling
- availability of information for making decisions
- risks involved with greywater recycling
- level of interest in sustainability and greywater recycling.

The incentives, drivers and attractions to rainwater harvesting and greywater recycling systems will be further investigated in the wider study to identify how the systems can become a more mainstream option in New Zealand buildings.

2.4 PERCEIVED BARRIERS TO UPTAKE

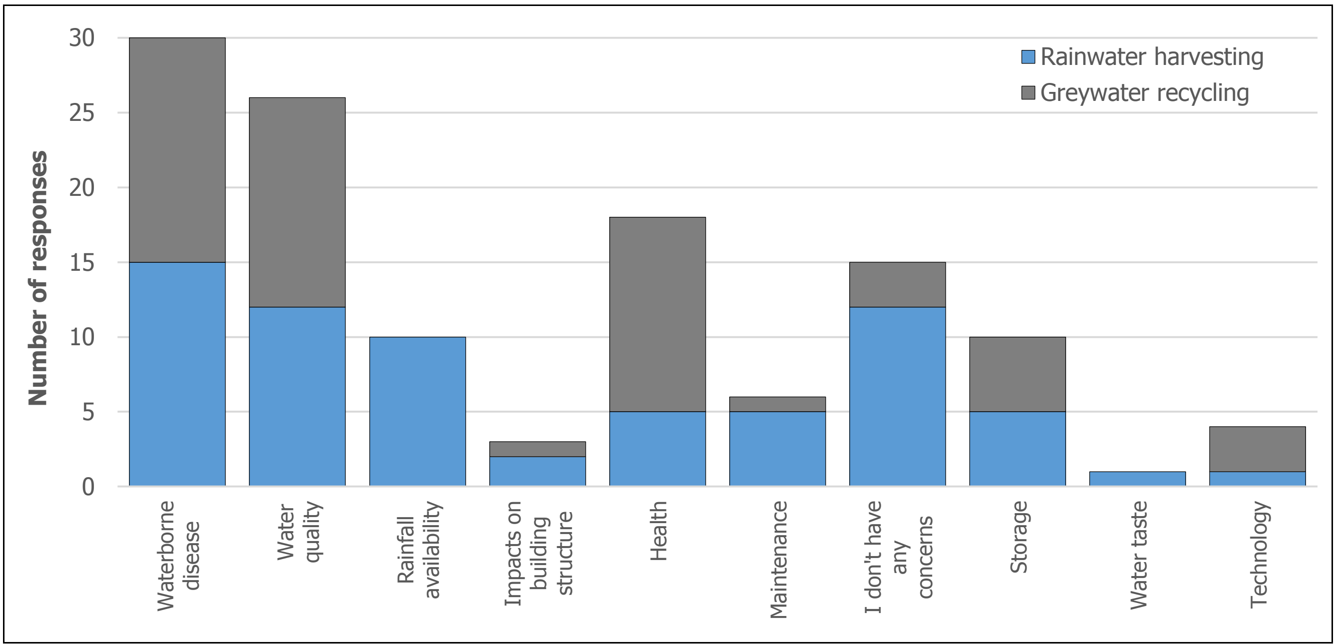
Interestingly, when asked what the biggest barriers were to rainwater harvesting and greywater recycling uptake, cost was the majority response, closely followed by lack of information and storage issues. For greywater recycling specifically, regulations and education were the two biggest barriers. These two issues go hand in hand in terms of information availability influencing regulations.

There are currently no national standards, guidelines, policies or consistency on greywater recycling throughout New Zealand. Upon discussions with local councils, the majority are using Auckland Regional Council's technical publication for on-site wastewater systems (TP58) (Ormiston & Floyd, 2004) as a reference point. This is perceived to prohibit the reuse of wastewater where provision to networked water and wastewater is available (recently under review). "Auckland Public Health Protection have expressed significant concerns about potential risks involved with the use of recycling systems in public or commercial facilities" (Ormiston & Floyd, 2004). Greywater is a subclassification of wastewater and therefore is unlikely to be able to be treated for reuse on site under TP58 without appropriate approval from relevant authorities.

Other places such as Kapiti Coast and Central Otago allow the use of greywater recycling for outdoor irrigation, but it is unable to be stored (Kapiti Coast District Council, 2015; Central Otago District Council, n.d.). Tauranga has allowed greywater recycling, but it cannot be stored or remain stagnant for more than 12 hours and only up to 1 m^3 per day can be discharged through subsurface irrigation (with several other caveats around this) (Tauranga City Council, 2016).

When the survey asked what the respondents' primary concerns were with rainwater harvesting and greywater recycling, responses overwhelmingly focused on water quality. As can be seen in Figure 4, waterborne disease, water quality and health were the top three issues of concern for respondents.

Figure 4: Primary concerns with rainwater and greywater systems.



While a large proportion of respondents also stated they did not have any concerns with using rainwater, waterborne disease was the primary concern with rainwater harvesting systems, followed by water quality. Similarly, waterborne disease was the primary concern with greywater systems, closely followed by water quality and health.

Framing the questions slightly differently using the word ‘barriers’ instead of ‘concerns’, the three biggest barriers with rainwater highlighted were cost, lack of information and storage issues. For greywater, the biggest barriers were the perceived lack of knowledge and the lack of or prohibitive regulations.

3 WATER QUALITY IN COMMERCIAL BUILDINGS

Ten commercial (retail, office and educational) buildings were selected and have agreed to undergo year-long investigations to understand in detail their water use, water savings, operation, reticulation systems, design issues and user benefits. The investigation is (at the time of writing in August 2016) 6 months completed.

Only one commercial building has been identified that has greywater recycling operational in New Zealand. Many buildings state they have greywater recycling. However, they actually mean rainwater harvesting – water they have collected from their roof during rainfall events.

Water and energy monitoring, the decision process, building occupant perceptions and other results from the building investigations research stream will be reported at the conclusion of the study. This paper specifically focuses on the water quality testing that is currently being undertaken to formulate an evidence-based response to the perceived barriers to uptake.

Although work has been undertaken on rainwater harvesting (Massey University, 2016) and greywater recycling (Centre for Integrated Biowaste Research (CIBR), 2016) in New Zealand already, these are focused on residential buildings with different study purposes.

3.1 TESTING METHODOLOGY

Water quality testing was incorporated into the case study investigations to explore the concerns around waterborne disease, water quality and health as a consequence of the survey concerns. Five of the case study buildings agreed to also have their water tested as detailed in Table 1:

Table 1: Case study buildings.

	A2	B1	C1	C3	W1
Systems	Rainwater	Greywater	Rainwater	Rainwater	Rainwater
Treatment		Sand and UV			
Building type	Office/storage	Retail	Office	Educational	Educational
Location type	Urban	Provincial	Provincial	Urban	Urban

The buildings with rainwater harvesting only collect their rainfall from the building roof and store it either within the basement or at ground floor level. The one building with both rainwater harvesting and greywater recycling collects water from the restroom wash hand basins and reuses it for toilet and urinal flushing as well as collected rainwater from the roof.

When assessing the buildings for potential contaminants, the list identified was:

- vehicle and machinery emissions
- animal faeces (both from roof and open tanks)
- material leaching
- building emissions (through on-site energy or heating, ventilation and air-conditioning (HVAC) plant)
- nearby construction activities.

Four of the buildings tested have a rainwater harvesting system feeding toilets, urinals and sometimes irrigation networks. These buildings are visited once per month over 12 months to take two 400 mL samples of water from the rainwater tank prior to any treatment process. All monthly samples are tested for *E. coli*, *Campylobacter* spp., *Salmonella* spp., pH, total suspended solids (TSS), ammonia (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitrogen (total N), phosphorus (total P), copper (Cu), zinc (Zn), aluminium (Al), boron (B), calcium (Ca), cadmium (Cd), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb) and sulphur (S).

The building with greywater recycling and rainwater harvesting is tested as per the other buildings on a monthly basis but samples are collected before and after treatment processes. Every 3 months, an additional 20 L of greywater is collected prior to the treatment processes, with 10 L tested for *Giardia* spp. and *Cryptosporidium* spp. and 10 L tested for culturable *Adenovirus*.

All of the above parameters were selected to provide an opportunity to analyse any impacts from climate and/or climate-influenced patterns (such as trees shedding leaves and more active birdlife).

3.2 GREYWATER QUALITY RESULTS

With one exception, all greywater samples were negative (i.e. below the assay detection limits) for all targeted microbes – *E. coli*, *Salmonella* spp., *Campylobacter* spp., *Giardia* spp., *Cryptosporidium* spp. and culturable *Adenovirus*. On month 3, *E. coli* was detected at 2.4 x 10^3 MPN/100 mL in the greywater that was sampled prior to the treatment process. The sample collected post-treatment had no detectable *E. coli*, indicating that the treatment process is effective in removing these microorganisms. There are no guidance values for greywater in New Zealand, so our results were compared to the expected range reported in literature. All chemistry parameters tested were consistently within or below the published range (Table 2).

Table 2: Comparison of greywater results with greywater data from published literature.

Parameter	Units	Range of results	Literature range	Reference
E. coli	**MPN/100 ml**	1–2.4 x 10^3	0–10^7	(Ottoson & Stenstrom, 2003)
***Salmonella* spp.**	**MPN/100 ml**	BDL	0–10^4	(Birks & Hills, 2007)
***Campylobacter* spp.**	**MPN/100 ml**	0.03–BDL	ND	
***Giardia* spp.**	**Cysts/10 L**	BDL	ND	
***Cryptosporidium* spp.**	**Oocysts/10 L**	BDL	ND	
Adenovirus	**IU/L**	BDL	ND	
pH		6.24–6.9	5–10	(Birks & Hills, 2007; Eriksson, et al., 2002)
Total suspended solids	**mg/L**	0.3–147	29–165	(Eriksson, et al., 2002; Gross, et al., 2015)
Ammonia (NH^{4+})	**mg/L**	BDL–4.48	0–11.3	(Eriksson, et al., 2002)
Nitrate (NO^{3-})	**mg/L**	BDL–9.55	0.4–17	(Eriksson, et al., 2002; Gross, et al., 2015)
Nitrite (NO^{2-})	**mg/L**	BDL–0.02	0.01–0.08	(Eriksson, et al., 2002; Paulo, et al., 2007)
Total nitrogen (N)	**mg/L**	0.41–11.69	8.7–21	(Eriksson, et al., 2002; Gross, et al., 2015)
Total phosphorus (P)	**mg/L**	BDL–0.162	0.1–57	(Birks & Hills, 2007; Eriksson, et al., 2002)
Sodium (Na)	**mg/L**	8.982–27.566	4.9–480	(Eriksson, et al., 2002)
Calcium (Ca)	**mg/L**	1.785–7.221	3.5–58	(Eriksson, et al., 2002; Gross, et al., 2015)
Magnesium (Mg)	**mg/L**	0.683–1.097	1.4–29	(Eriksson, et al., 2002; Gross, et al., 2015)
Copper (Cu)	**mg/L**	0.044–0.264	<0.05–0.3	(Eriksson, et al., 2002)
Zinc (Zn)	**mg/L**	0.038–0.22	0.2–6.3	(Eriksson, et al., 2002)
Aluminium (Al)	**mg/L**	BDL–0.05	<1–21	(Eriksson, et al., 2002)
Boron (B)	**mg/L**	0.01–0.072	<0.1–0.5	(Eriksson, et al., 2002)
Cadmium (Cd)	**mg/L**	BDL	<0.06–2.5	(Surendran & Wheatley, 1998)
Iron (Fe)	**mg/L**	BDL–0.109	0.34–1.1	(Eriksson, et al., 2002)
Potassium (K)	**mg/L**	1.838–12.247	1.1–59	(Eriksson, et al., 2002)
Manganese (Mn)	**mg/L**	BDL–0.009	0.03	(Eriksson, et al., 2002)
Nickel (Ni)	**mg/L**	BDL–0.042	1.3–28	(Surendran & Wheatley, 1998)
Lead (Pb)	**mg/L**	BDL	0.03–6.9	(Eriksson, et al., 2002; Surendran & Wheatley, 1998)
Sulphur (S)	**mg/L**	0.834–5.491	1.2–72	(Eriksson, et al., 2002; Gross, et al., 2015)

BDL: below detection limit. ND: not detected. MPN: most probable number.
Detection limits are as follows: E. coli *1 MPN/100 ml;* Salmonella *spp. 2 MPN/100 ml;* Campylobacter *spp. 2 MPN/100 ml;* Giardia *spp. 1 cyst/10 L;* Cryptosporidium *spp. 1 oocyst/10 L; culturable* Adenovirus *1 IU/L.*

3.3 RAINWATER QUALITY RESULTS

As the results of the survey highlighted in Figure 2, 49% of respondents would find drinking rainwater to be acceptable. The results of the water testing in this study were compared to both the World Health Organisation's

Guidelines for drinking-water quality and the Ministry of Health's *Drinking-water standards New Zealand 2005* (DWSNZ), as indicated within Table 3.

One of the buildings, C3, has consistently tested positive for *E. coli* each month (range 49–8,500 MPN/100 ml). Another site, A2, had 16 *E. coli* MPN/100 ml on one occasion (month 6), but otherwise, that site and all other sites were negative for *E. coli*, *Campylobacter* spp. and *Salmonella* spp.

Another of the buildings, W1, has consistently contained higher levels of metals than would be permitted by these drinking water limits, particularly with regard to Zn, Fe, Ni and Pb. In this particular case, there is a significant amount of construction activity immediately adjacent to the building, which may be the source of these increased metal levels.

All other sites were comfortably within the required limits for all parameters.

Table 3: Comparison of rainwater results with the DWSNZ and WHO drinking water guidelines.

Parameter	Units	WHO (World Health Organisation (WHO), 2011)	DWSNZ (Ministry of Health, 2008)	Range of results
E. coli	**MPN/100 ml**		1	BDL–8.5 x 10^3
***Salmonella* spp.**	**MPN/100 ml**			BDL
***Campylobacter* spp.**	**MPN/100 ml**			BDL
pH		NS	7–8*	4.96–7.79
Total suspended solids	**mg/L**			0–456
Ammonia (NH^{4+})	**mg/L**		1.5*	BDL–1.49
Nitrate (NO^{3-})	**mg/L**	50	50	BDL–1.23
Nitrite (NO^{2-})	**mg/L**	3	3	BDL
Total nitrogen (N)	**mg/L**			BDL–3.3
Total phosphorus (P)	**mg/L**			BDL–0.141
Sodium (Na)	**mg/L**	NS	200*	1.243–24.549
Calcium (Ca)	**mg/L**			BDL–10.383
Magnesium (Mg)	**mg/L**			0.132–2.906
Copper (Cu)	**mg/L**	2	2	0.001–0.086
Zinc (Zn)	**mg/L**	NS	1.5*	0.032–4.145
Aluminium (Al)	**mg/L**	NS	0.1*	BDL–0.038
Boron (B)	**mg/L**	2.4	1.4	0.01–0.09
Cadmium (Cd)	**mg/L**	0.003	0.004	BDL
Iron (Fe)	**mg/L**	NS	0.2*	BDL–7.226
Potassium (K)	**mg/L**	NS		0.11–2.032
Manganese (Mn)	**mg/L**	NS	0.4	0.01–0.059
Nickel (Ni)	**mg/L**	0.07	0.08	BDL–0.368
Lead (Pb)	**mg/L**	0.01	0.01	BDL–0.145
Sulphur (S)	**mg/L**	NS	250*	0.18–3.933

** guideline value for aesthetic purposes. MPN: most probable number. NS: none stated*

In general, the results to date show that the greywater samples are within the expected ranges. The rainwater samples from all buildings are typically within the respective guideline limits for drinking water, except for building W1 between months 3 and 5 with increase metal traces.

The levels of *E. coli* are generally low, and all other microbial parameters are consistently negative. Although *E. coli* may not reflect the presence or absence of all pathogens, it is the best available indicator organism and is the industry standard indicator organism for faecal contamination.

4 IMPACTS ON HUMAN HEALTH

So what does all of this mean, especially if the rainwater and/or greywater is only being used in toilets and urinals (non-potable, non-contact uses) in commercial buildings?

After 12 months of testing the water quality in these five commercial buildings around New Zealand, the data will be used to produce a thorough risk assessment. Due to this paper presenting only the preliminary findings, the results from the risk assessment will be available at the conclusion of the study to understand the impacts on human health, if any.

5 CONCLUSIONS

From the 71 self-selected survey respondents, the primary concern was by and large the water quality within rainwater harvesting and greywater recycling systems. However, education, regulations and cost were the largest barriers perceived by respondents. This is confirmed with the CIBR stakeholder survey findings also (refer section 2.3).

To understand this in more detail, rainwater and greywater from five case study buildings are being tested against the World Health Organisation's *Guidelines for drinking-water quality,* the Ministry of Health's Drinking-water standards for New Zealand and other published literature. The preliminary results indicate that the metal and microbial parameters tested are generally within the expected ranges for rainwater and greywater.

Although the risk assessment is yet to take place, the severity of water quality risks from rainwater and greywater appear to be minor at this preliminary stage. This will be confirmed via a thorough risk assessment at the conclusion of the 12-month water quality testing programme. The study will conclude in March 2017, and the final results of both the water quality testing study and the overall study will be published shortly after.

The results from the survey and the water quality testing demonstrate a potential educational gap between perceived and actual water quality in these two alternative water use systems. Greater awareness about the systems would be beneficial, specifically around the risks of non-maintenance and treatment regimens, where the biggest issues and concerns are founded.

In conclusion, New Zealand-specific evidence-based information, guidelines and regulations are needed to overcome the perceived concerns and barriers to uptake of rainwater harvesting and greywater recycling systems. A consistent, nationwide approach would contribute to this.

ACKNOWLEDGEMENTS

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