ADDING CLARITY TO THE MURKY WORLD OF GREYWATER RE-USE

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ABSTRACT

A large proportion of residential and commercial water use could potentially be substituted with alternative water sources, such as greywater. In the Kapiti Coast area it has been reported that 68% (160 Litres /per person/day) of residential water demand is water that is available for re-use. If re-used this represents a large proportion of a household's daily water use, that does not need to be sourced from the reticulated network. Greywater reuse provides benefits for both property owners and water service providers. Using alternative water sources has the potential to reduce network demand and increase resilience, reduce wastewater peak flows and could allow outdoor water use to continue in periods of drought.

Given the increase in water shortage experienced across New Zealand, alternative solutions to the reticulated network should be assessed for their suitability for reuse. However, there are several barriers to uptake of greywater re-use that require more research. Predominantly, people's perception of risk from waterborne disease, water quality and human health risk were identified in a 2014 industry survey as the biggest barrier to greywater re-use in New Zealand. A subsequent water quality and human health risk analysis found better than expected water quality results, although it was highlighted that more work was required to make this representative.

A further barrier to uptake is lack of legislation, with inconsistent guidance for home and business owners regarding re-use of greywater throughout New Zealand. A 2011 survey of regional councils found that the majority permit the discharge of greywater to land without a resource consent. However, it was found that some of these regional councils deal only with discharge to land, and not re-use of greywater. In these instances, re-use was reported to be a function of the district council. On the contrary, many of the district councils that responded considered greywater re-use to be a function of the regional council. Thus, highlighting the inconsistencies. There are no national guidelines for greywater re-use at present.

This study seeks to expand on previous research by assessing microbial water quality from a range of greywater sources, including greywater from both residential and commercial properties. Taken weekly, over six months, greywater samples were tested for *Escherichia coli (E. coli)* and *Pseudomonas aeruginosa (P. aeruginosa)* and compared to international greywater reuse guidelines.

It is the overall aim that this research will provide more context around greywater re-use and any potential impacts to human health, informing future legislation and recommendations across New Zealand.

KEYWORDS

GREYWATER, RE-USE, WATER, RECYCLING, RESIDENTIAL, COMMERCIAL, HUMAN HEALTH

PRESENTER PROFILES

Amber Garnett is an environmental scientist at BRANZ. She has a Master's in Environmental Management from Massey University. A strong research theme to date has been resource management, in particular freshwater.

Vikki Ambrose is a scientist at ESR. She has a Master's degree in Cell and Molecular Biosciences and performs research in biowaste; environmental water virology, developing sustainable options for the reuse of biowastes; the microbial quality of greywater; riparian planting and water quality restoration.

1 INTRODUCTION

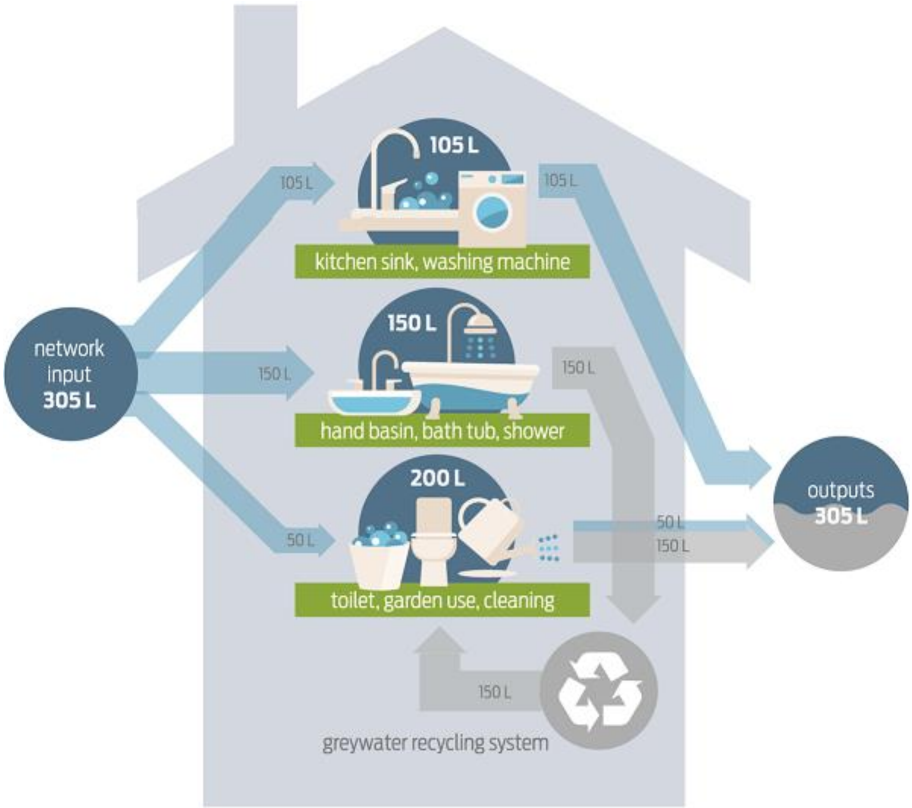
Water is widely considered to be in abundant supply in New Zealand as a result of low population densities and high annual rainfall. In fact, the total freshwater available per person in New Zealand is reportedly higher than 180 other countries (Minstry for the Environment, 2007). Amongst OECD countries New Zealand was ranked fourth for freshwater availability. However, New Zealanders use on average two to three times more freshwater per person that most other OECD countries (Minstry for the Environment, 2007).

Freshwater supply in some areas of New Zealand experiences stress for part or all of the year (Ministry for the Environment, 2010). It is common during the summer months for residential water restrictions to be implemented that restrict outdoor water use. Nearly half (44%) of participants in the National Performance Review reported implementing water restrictions in some or all of their districts during the 2016/17 period (Water New Zealand, 2017).

Increasing social, environmental and economic pressures, such as population increases, water shortages and infrastructure costs have meant a growing interest in water reuse options, and alternative water sources; such as rainwater harvesting, and greywater re-use. Greywater is increasingly being recognized as a potential alternative source of water for non-potable end uses in both residential and commercial property.

Greywater is commonly defined as untreated wastewater from a property excluding toilet water (which is known as blackwater) and will often exclude discharges from the kitchen due to high organic matter levels. As can be seen in Figure 1, greywater generated from hand-basins, bathtubs and showers can be re-used for activities such as toilet flushing and sub-surface garden irrigation (but is not recommended for use on vegetable gardens) in both commercial and residential properties.

Figure 1: Schematic of a residential greywater recycling system showing potential sources and end uses



Greywater recycling in both residential and commercial properties can have a range of potential benefits for both property owners and water service providers (if implemented and managed correctly) (Bint & Jaques, 2017: Casanova, et al., 2001). Potential benefits include:

- Reducing the volume of wastewater to be treated (which has financial and environmental benefits)
- Positive cost-benefits of greywater reuse for both home owners (if metered) and water service providers
- Reducing demand during peak periods
- Freeing up capacity in wastewater and water supply for future growth, thus potentially extending the timeframe for infrastructure upgrades
- Providing resilience in the event of a natural disaster/ emergency
- Supporting garden irrigation year-round (e.g. during water restrictions)

Furthermore, the consequences of separating and reusing greywater are being viewed as important to improve the functioning of on-site wastewater treatment system (Siggins et al*.,* 2012).

Although greywater recycling is more commonly practiced overseas, few territorial authorities such as the Kapiti Coast actively require homeowners to have an alternative supply such as rainwater harvesting or greywater recycling. Whilst greywater recycling systems are actively encouraged in the district, it is reported that the uptake of greywater recycling systems compared with rainwater harvesting systems is lower. A 2014 BRANZ industry survey identified three prominent barriers to uptake of these systems to be water borne disease, water quality and health (Bint & Jaques, 2017). At present in New Zealand there is no national guideline for greywater recycling systems.

This paper will discuss the findings of a joint research project between BRANZ and ESR that aimed to investigate the microbial quality of greywater from various sources in both commercial and residential properties, over a period of two- six months.

It was hypothesised that from a microbiological perspective, exposure to new pathogens is more likely in commercial properties for two reasons. Firstly, commercial sources of greywater, such as hand-basins will have a greater number of people contributing to the sample, and thus an increased likelihood of detecting pathogens in greater concentrations. Secondly, in contrast to residential properties where the exposure to any pathogens is limited to members of one household (who are likely the original source of the pathogen), in commercial properties there is the potential to be exposed to a range of pathogens from other individuals (ESR, 2013).

2 MATERIALS AND METHODS

2.1 SAMPLE SELECTION

Greywater from several sources in both residential and commercial properties were sampled weekly, over a period of two to six months (depending on the property). A total of eight residential properties were sampled, sources of greywater included hand-basins, showers and washing machines. A total of two commercial properties were sampled, sources of greywater included hand-basins, and in one of the properties, the showers. Table 1 assigns each of the residential and commercial properties sampled with a unique identifier to ensure anonymity. Properties 1-8 are residential and properties 9-10 are commercial. The numbers correspond to the number of weekly samples taken from the respective source for each property.

Table 1 Participant identifiers and corresponding samples collected

Property	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Shower sample	*19*	*12*	*11*	*13*					*6*	
Basin sample		*12*		*13*	*7*	*7*	*8*	*9*	*14*	*12*
Laundry sample					*5*		*6*	*1*		

Of the eight residential properties samples properties 1 and 3 had operational greywater systems in place.

Property 1 utilises a Waterflow NZ- Natural Flow Ecowaste and Sewage system. Rainwater collected from the roof is stored in rainwater tanks and pumped to the shower. Post shower, the water runs down the drain and into pipes which converge into a gulley trap before going out to a greywater tank to be filtered and then out onto their own land via a dispersal field. A separate black water circuit feeds into a tank that contains natural filter materials and tiger worms that process the solids. The treated liquids also go to the dispersal field. Both black and grey water systems are gravity fed.

In Property 3 rainwater is captured, stored and pumped in to the house for non-potable uses (toilet flushing and irrigation). Shower, bath and hand basin water is captured in a small 40 litre greywater tank. This greywater is then immediately pumped through a piping system and used for surface and sub-surface irrigation of the garden. If showers and wash basins are not in use, the pump is not activated.

Samples from these properties were collected prior to treatment. The remainder of residential sampling points were properties on town water supplies and were also sampled untreated, and from source.

2.2 EXPERIMENTAL DESIGN

Sampling protocols were developed separately for residential and commercial properties and were standardised across all properties of the same typology.

Weekly greywater samples, per source, were collected by the corresponding homeowner or a representative from each commercial property. All samples were collected during a greywater event (for example, a shower or hand-wash), and directly from source (i.e. the greywater was captured and stored prior to entering the wastewater network). Samples were transported on ice to the laboratory for storage at 4°C and tested within 24-hours of collection.

Each residential sample was analysed individually, whereas for the commercial properties several sampling points were established throughout the properties (to ensure the samples were representative). Commercial samples, per property, were combined to provide one composite sample per week from each property.

2.3 LABORATORY ANALYSIS

Samples were analysed for total coliforms and *E. coli* using the *colilert* ® testing method from IDEXX. *E. coli* is an indicator of faecal contamination and is typically used as an indicator of water quality and public health risk. Positive samples were detected by fluorescence viewed under UV light. Results indicate the most probable number of *E. coli* present in the 100 ml sample.

Samples were also analysed for *P. aeruginosa* using the *Pseudolert* ® testing method, also from IDEXX. *P. aeruginosa* is a pathogenic microorganism commonly found in greywater (Maimon *et al.,* 2014). It is ubiquitous in the environment, living on inert and living (i.e. human and plant tissue) matrices (Botzenhart and Doring, 1993). *P. aeruginosa* can have negative effects on the environment (e.g. medical device, premise-plumbing), attaching to surfaces (Borel et al 2017) and is recognized as an emerging opportunistic pathogen of clinical significance. Positive samples were detected by blue fluorescence under at 365 nm UV light. Results indicate the most probable number of *P. aeruginosa* present in the 100 ml sample.

The results from *Colilert* ® and *Pseudolert* ® tests were calculated using MPN tables incorporated in the IDEXX method. In the corresponding figures (figures 2-7) results <1 MPN/100 ml are represented as 0.1 MPN/100 ml. Due to the high variability of the results this paper has chosen to display each sampling event separately instead of calculating as averages.

The upper threshold of the IDEXX method for both *E. coli* and *P. aeruginosa* is >2419.6 MPN/100ml. Results that were above this threshold were retested after being diluted 1:100 or 1:10 respectively, and the appropriate dilution factor was applied in calculations. This allowed the most probable number *E. coli* and *P. aeruginosa* numbers to be calculated.

Results >2419.6 MPN/100ml in figures 2 to 7 refer to those samples that were measured above this threshold. It is important to note that some dilutions were not possible and therefore results are shown at 2419.6. MPN/ 100 ml.

Where no results are shown for a property this indicates that no samples were collected from that source for that particular property.

3 RESULTS

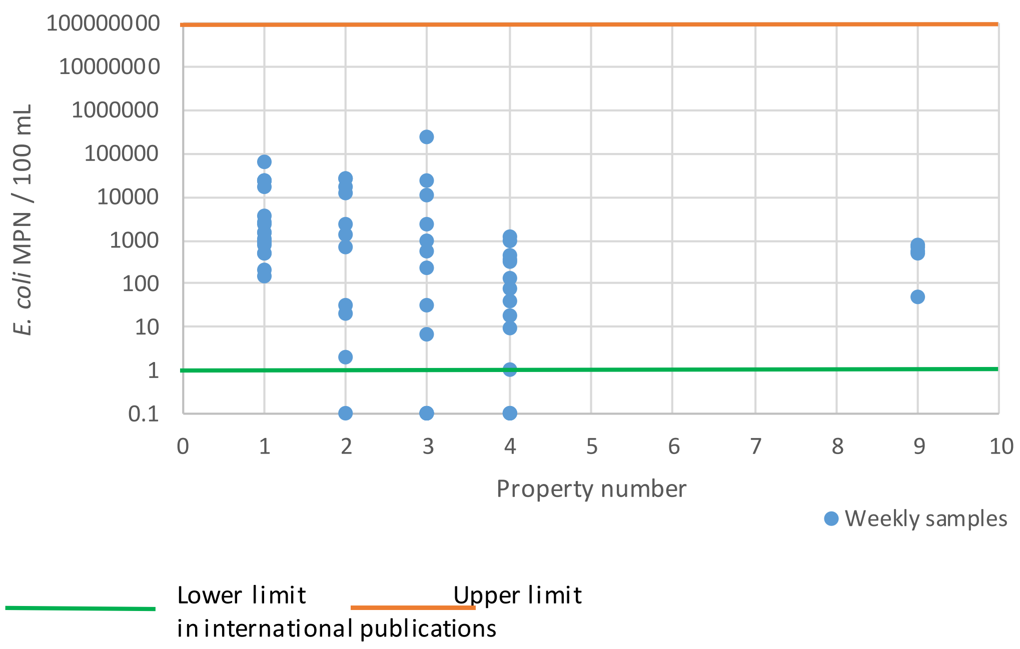
3.1 GREYWATER SOURCED FROM RESIDENTIAL AND COMMERCIAL SHOWERS

The greywater from four residential showers and one commercial shower was sampled. For the commercial property 5 samples were collected, with the same 1-3 people contributing each week. This sample is therefore more representative of a residential property sample than a true commercial sample. Between 5 and 19 samples per residential property were collected across the monitoring period.

3.1.1 E. COLI

As can be seen in Figure 2 the residential shower samples showed wide variability of *E. coli* numbers both from week to week for the same contributor, and between contributors. The *E. coli* numbers from properties 2 and 3 showed the greatest variation from week to week. Samples taken from property 3 for example, ranged from <1 MPN/100ml to 2.4×10^5 MPN/100ml. Property 9 had the most consistent numbers of *E. coli*, with the least variation across sampling events. However, it should be noted that this property had less sampling events than other samples (refer to Table 1). Properties 1 and 3 both have greywater systems installed.

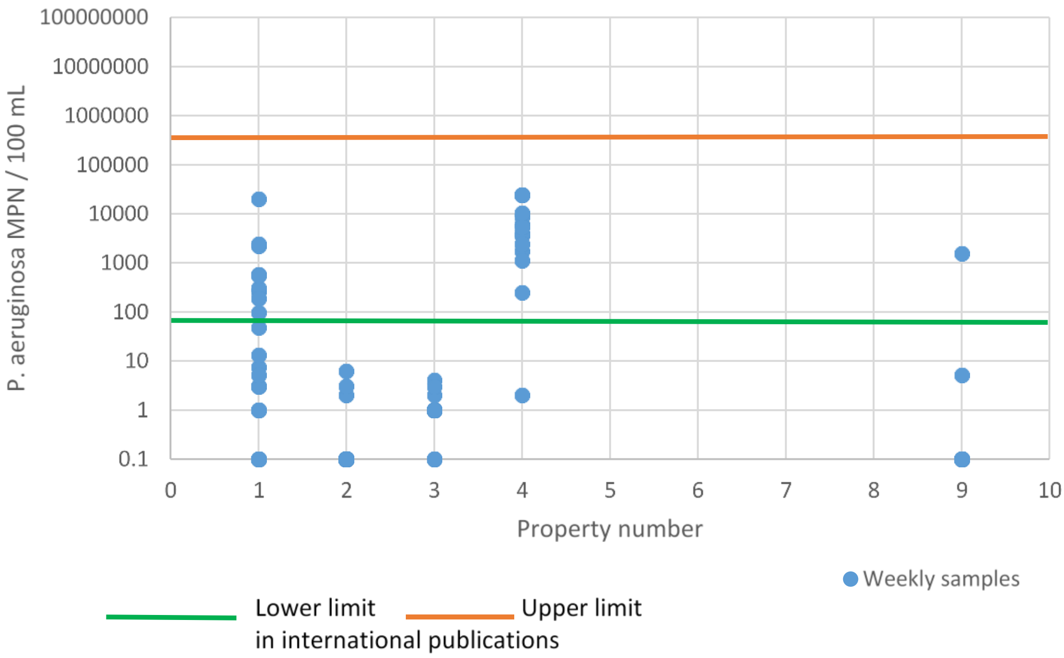
Figure 2 E. coli results from shower samples compared with international publication lower and upper thresholds (Leonard and Kikkert, 2006).



3.1.2 P. AERUGINOSA

Figure 3[1] shows properties 2 and 3 had the most consistent numbers of *P. aeruginosa*, ranging only between <1 and 6 MPN/100 ml, and <1 and 4 MPN/100 ml respectively. Both properties 2 and 3 had consistent *P. aeruginosa* numbers lower than the stipulated threshold determined by Benami, et al (2016) and Casanova, et al (2001). Property 4 had the most variation ranging from 2 to 2.4 x 10^4 MPN/100 ml. There is wide variability of *P. aeruginosa* numbers both from week to week for the same contributor, and between contributors. Interestingly, the lowest numbers of *P. aeruginosa* were found in residential shower samples, which is in contrast to the *E. coli* numbers (Figure 2), and low when compared to international studies at 94 - 3.1 x 10^4 CFU/ 100 mL (Benami *et al* (2016) and 200 -1.6 x 10^5 CFU/ 100 mL (Casanova *et al* (2001).

Figure 3 P. aeruginosa results from shower samples compared with international publication lower and upper thresholds (Benami et al 2016; Casanova et al 2001).



3.2 GREYWATER SOURCED FROM RESIDENTIAL AND COMMERCIAL HAND-BASINS

The greywater from six residential hand-basins and two commercial properties were sampled. Between 5 and 19 samples per residential property were collected across the monitoring period (see Table 1). Of the two commercial properties contributing to basin samples, weekly composite samples from property 9 included 11 hand-basin samples and weekly composite samples from property 10 included two hand-basin samples. For each

[1] Note: there was an unexplained issue with the dilutions on the Pseudalert counts with some high levels of *P. aeruginosa*, where the initial counts were >2419.6 MPN/100ml (maximum count). This required further dilution to repeat the count. Results from these dilutions were sometimes negative. The initial Pseudolert mixtures in the count trays were then confirmed as *P. aeruginosa* using an oxidase test. The reason for the dilution negatives is unknown at this stage and is an anomaly being investigated by IDEXX.

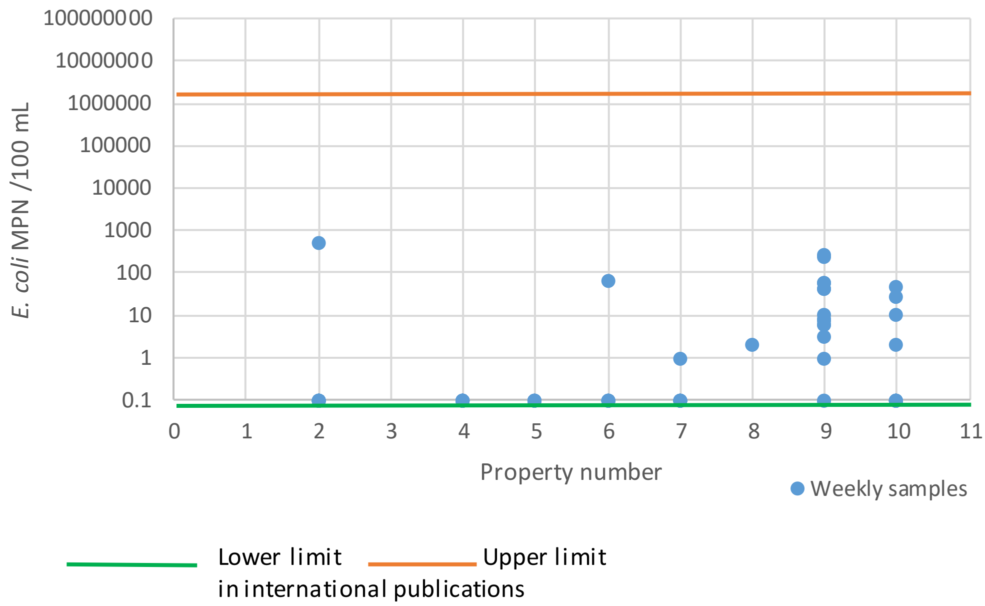
commercial property the individual hand basin samples were combined and mixed well to give one composite sample per property per week.

3.2.1 E. COLI

As can be seen in Figure 4 the *E.coli* numbers measured in residential hand-basin samples were low, with only 8% of samples (4/50) exceeding the detection limit of 1 MPN/100ml. The remaining 46 samples had detection limits less than <1 MPN/100ml. Of the four positive resdiential samples *E. coli* numbers ranged from 1 MPN/100ml in property 7 to 547 MPN/100ml in property 1.

The commercial properties had a range of *E. coli* numbers ranging between <1 and 290 MPN/100 ml from property 9, and *E. coli* numbers ranging between <1 to 47 MPN/100 ml from property 10, with nine of the 13 samples at <1 MPN/100 ml. The difference between the results from commercial property 9 and 10 could be due to a smaller number of basins being sampled in property 10, and fewer contributors to each basin from the smaller area of the property being sampled. When compared to the results of Birks & Hills (2007) all samples were well below the upper values.

Figure 4 E. coli results from hand-basin samples compared with international publication lower and upper thresholds (Birks et al, 2004).

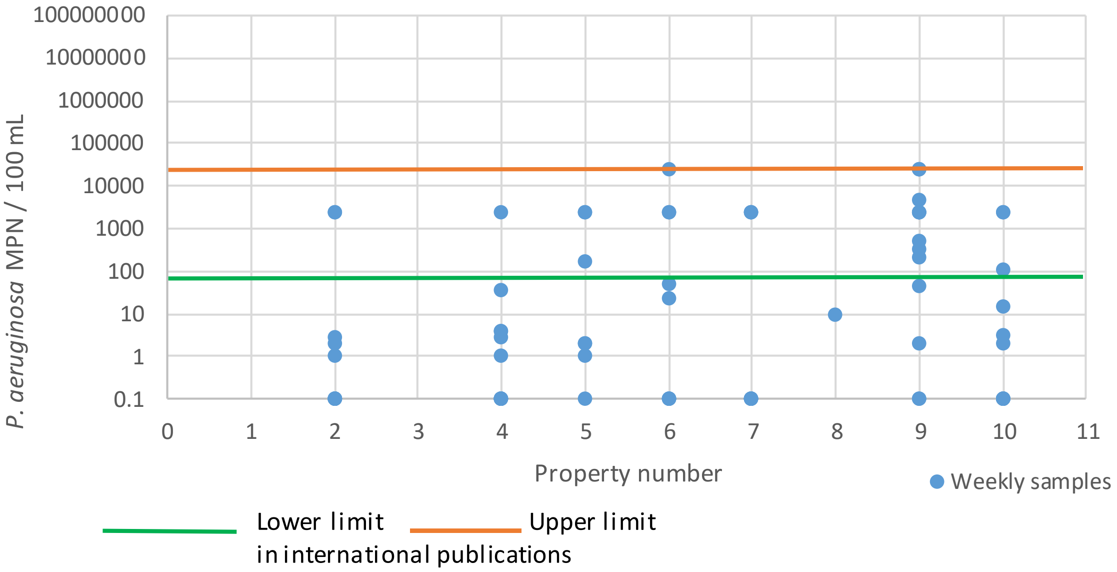


3.2.2 P. AERUGINOSA

Figure 5 shows levels of *P. aeruginosa* were varied in all residential hand-basin samples, with 46% of samples (23/50) testing positive for *P. aeruginosa.* Overall in the residential basin samples for *P. aeruginosa*, 80% were below 200 MPN/100 ml and 20% were above the threshold limit (prior to dilution) of the testing methodology at >2419.6 MPN/100 ml (refer to section 2.3). Notably, properties 6 and 9 had a single sample that bordered results found by Benami, et al. (2016), with these two properties displaying the most variation from week to week.

Of the two commercial properties samples, property 10 had *P. aeruginosa* numbers that were more consistent with the results found in the residential properties. With 78% at below 200 MPN/100 ml and 15% at >2419.6 MPN/100 ml, this was probably due to the number of contributors also being more representative of a residential property.

Figure 5 P. aeruginosa results from hand-basin samples compared with international publication lower and upper thresholds (Benami et al 2016).

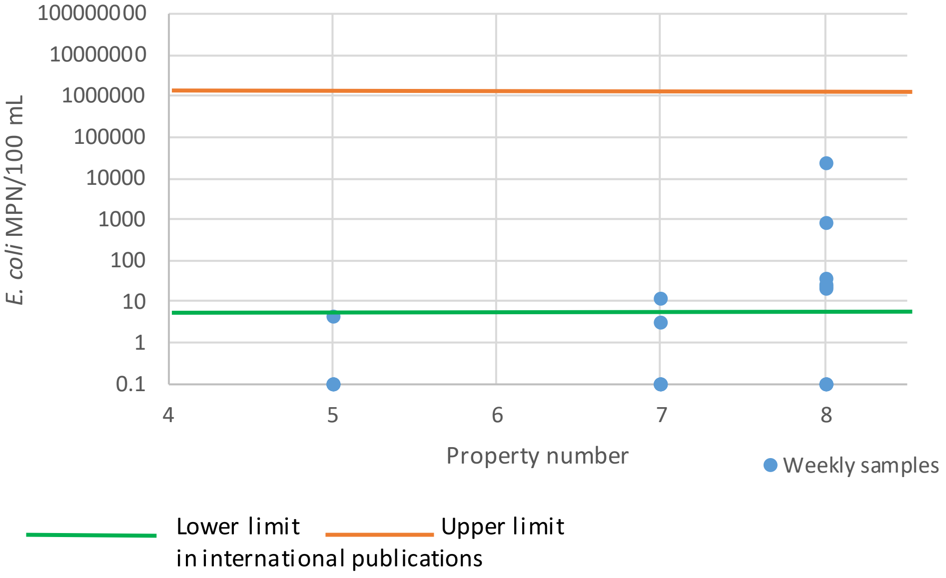


3.3 GREYWATER SOURCED FROM RESIDENTIAL LAUNDRIES

3.3.1 E. COLI

Of the ten properties only three contributed samples from the laundry, more specifically the washing machine. No commercial laundries were sampled. Of the three contributing properties between 5 and 10 samples were collected. It can be seen in Figure 6 that Property 5 had only one positive *E. coli* numbers of 4 MPN/100 mL, with the remaining four samples at <1 MPN/100 mL. Similarly, property 7 had two positive *E. coli* numbers of 12 and 3 MPN/100 mL, with the remaining four numbers at <1 MPN/100ml. Finally, property 8 showed 6 positive *E. coli* numbers ranging from <1 to 2.4 x 10^4 MPN/100 ml. When compared to the results of O'Toole, et al. (2012) all samples were below the upper values.

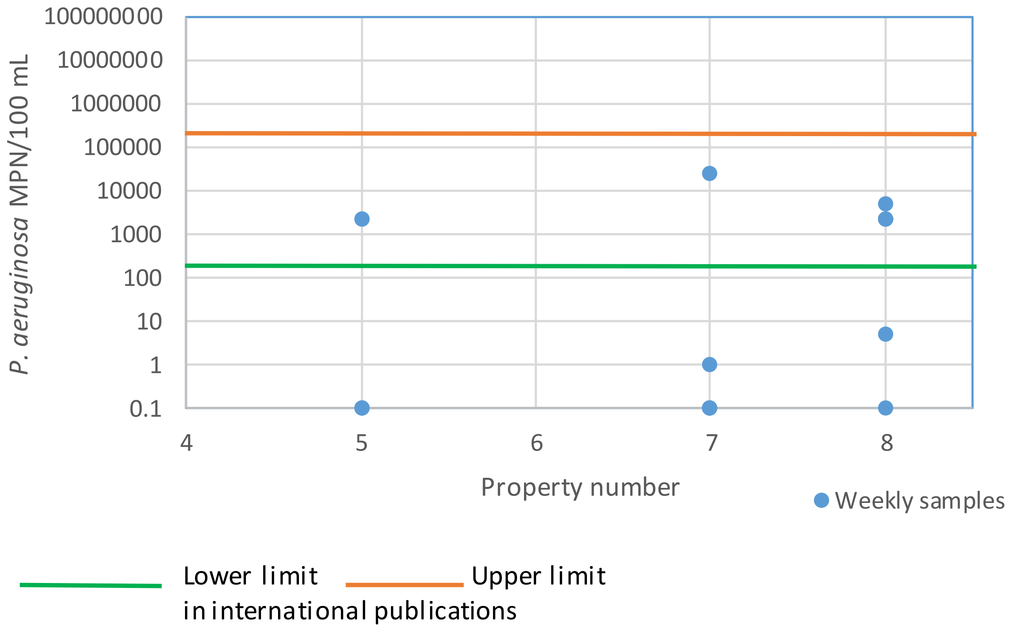
Figure 6 E. coli results from laundry samples compared with international publication lower and upper thresholds (O'Toole et al 2012)



3.3.2 *P. AERUGINOSA*

There appears to be a lot of variation in laundry sample results between properties and within the same properties from week to week (Figure 7). This is demonstrated clearly for property 5, in which *P. aeruginosa* numbers range from <1 to 2419.6 MPN/100ml. Properties 5 and 7 had only one and two high sample numbers, respectively. Whereas Property 8 repeatedly had high *E. coli* numbers for 6/10 samples with 9/10 positive *P. aeruginosa* results. When compared to the results of Casanova, et al. (2001) all samples are below their upper values with the majoirty of samples below the lowest values observed in the study.

Figure 7 P. aeruginosa results from laundries compared with international publication lower and upper thresholds (Casanova et al 2001).



4 DISCUSSION

4.1 INTERNATIONAL COMPARISON OF THE VARIATION BETWEEN SOURCES OF GREYWATER

4.1.1 E. COLI

Greywater from a range of sources in both residential and commercial properties was analysed over a two to six-month period (depending on the property) for both *E. coli* and *P. aeruginosa*. Whilst there are currently no national guidelines for greywater recycling in New Zealand the *E. coli* results from this research are compared to guideline values implemented in Southern Australia (Table 2). These guidelines are also consistent with the microbial criteria implemented in the state of Victoria's greywater guidelines *(Environmental Protection Agency, 2003).*

Table 2 Classification of reclaimed water for use in South Australia *(Department of Humans Services & Environmental Protection Agency, 1999)*

Class	Uses	Microbiological criteria E. coli/100ml (median)
A	Primary contact recreation	<10 Specific removal of viruses, protozoa and helminths may be required
	Residential non-potable	
	- garden watering	
	- toilet flushing	
	- car washing	
	- path/wall washing	
	Municipal use with public access/adjoining premises	
	Dust suppression with unrestricted access	
	Unrestricted crop irrigation	
B	Secondary contact recreation	<100 Specific removal of viruses, protozoa and helminths may be required
	Ornamental ponds with public access	
	Municipal use with restricted access	
	Restricted crop irrigation	
	Irrigation of pasture and fodder for grazing animals	
	Washdown and stock water	
	Dust suppression with restricted access	
	Fire fighting	
C	Passive recreation	<1,000 Specific removal of viruses, protozoa and helminths may be required
	Municipal use with restricted access	
	Restricted crop irrigation	
	Irrigation of pasture and fodder for grazing animals	
D	Restricted crop irrigation	<10,000 Specific removal of viruses, protozoa and helminths may be required
	Irrigation for turf production	
	Silviculture	
	Non-food chain aquaculture	

The results from this study were assessed against the *E. coli* requirements of the Southern Australian guidelines, and can be seen in Table 3

When compared with the *E. coli* thresholds established in the Southern Australia guidelines for reclaimed water use, it can be seen that for both residential and commercial properties the hand-basin and laundry sample *E. coli* numbers are consistent with category A reclaimed water. In accordance with Table 2, class A reclaimed water in Southern Australia can be used for residential non-potable uses such as toilet flushing, garden watering and exterior washing, amongst other end-uses.

International findings for *E. coli* in laundry samples have been shown to be as high as 10^7 (Katukiza et al. 2015), so levels found in this study are comparatively low with international findings.

Properties 1 and 2 had *E. coli* numbers from shower samples that were consistent with class D reclaimed water, and properties 4, 5 and 9 consistent with class C reclaimed water. The potential end-uses for these sources of greywater are restricted. Class D reclaimed water would be suitable for fewer uses, such as restricted irrigation and non-food aquaculture. It would not be suitable according to the Australian guidelines for garden watering or toilet flushing. Of interest, property 1 has an established greywater system that is filtered (after our sampling point) and is sub-surface irrigated to a dispersal field on the property. Property 3 also has a greywater system which is used for sub-surface and some surface irrigation.

Compared with the international findings of Leonard and Kikkert (2006), the *E. coli* numbers from the shower at property 1 (2.4×10^5 MPN/100 ml) are not exceedingly high compared their findings of $1\text{-}1.4 \times 10^7$ /100 ml (sampled from various countries including NZ), and of Birks and Hills (2007) at 3.9×10^5/ 100 ml (UK). Studies suggest that *E. coli* numbers in greywater can be as high as 10^8 CFU/100 ml (Birks *et al*., 2004; Leonard & Kikkert, 2006), therefore the numbers detected in this study appear to be relatively low by international standards.

Table 3 Results compared with the categories for reuse as stipulated in the Australian guidelines for reclaimed water use

Property	1	2	3	4	5	6	7	8	9	10
Shower sample	X	X	X	X					X	
Basin sample		X		X	X	X	X	X	X	X
Laundry sample					X		X	X		

Interestingly, the Australian guidelines prescribe a minimum level of treatment for reclaimed water. Primary sedimentation or an equivalent process for removal of solids, plus a stabilization process such as lagooning or full secondary treatment is recommended. It is noted that untreated wastewater is not to be used and primary treated wastewater will rarely be approved for reuse (Department of Humans Services & Environmental Protection Agency, 1999). It is worth noting that in this study all the hand basin and laundry samples tested were from source and pre-treatment and were found to have *E. coli* numbers consistent with the guidelines for class A reclaimed water.

This suggests that with treatment there would likely be no barrier in terms of *E. coli* for using the hand-basin and laundry water sampled, and that following treatment the *E. coli* number found in both residential and commercial showers would be reduced, with the potential of increasing the reuse possibilities in accordance with the guideline recommendations.

4.1.2 LIMITATIONS

It is important to note however, that whilst the median *E. coli* numbers of each property are consistent with the *E. coli* requirements for class A reclaimed water, during this study no testing was conducted for other bacterial species, viruses, protozoa or helminths, such as those also required in international guidelines. *E. coli* may not reflect the presence or absence of all pathogens, but it is the industry standard indicator organism for faecal contamination.

Therefore, whilst our results are consistent for *E. coli* there is no data with which to compare the other variables that are requirements of the guidelines. Thus, warranting further investigation to be conclusive. Furthermore, following the guideline recommendation the classification of results is based on the median sample. However, we noted large variations between sampling points and between properties and would therefore exercise caution with any recommendations until further testing has been performed.

4.1.3 *P. AERUGINOSA*

There are no standards for levels of *P. aeruginosa* in greywater for reuse in New Zealand, but in Germany, the standard for *P. aeruginosa* is 100 CFU/ 100 ml (Winward et al. 2008).

4.1.4 CONCLUSIONS

Across two to six months greywater was sampled from source at eight case study buildings. Residential and a commercial shower, hand-basins and residential laundries were all tested for *E. coli* and *P. aeruginosa.* This study found great variation between samples of the same property and between properties. When compared with the Southern Australian guidelines most samples were consistent with class A reclaimed water (with regards to the *E. coli* concentrations). Although more research is needed to be conclusive.

The high variability of samples per property, and also between properties sampled throughout the study means that caution should be taken with any reuse recommendations at this time and prior to further testing being carried out. Based on this variation between sources it is recommended that decisions surrounding greywater reuse should currently be made on a case to case basis, but sub-surface irrigation is recommended to reduce risks from exposure. Due to the consistently higher numbers of *E. coli* and *P. aeruginosa* found in showers we would recommend shower greywater be treated prior to reuse.

This research was not able to answer the original hypothesis as the commercial samples obtained were not representative of true commercial samples. Only one of the commercial properties had sufficient volumes of both sources and contributors for hand basin collections. This means that the data obtained in this study is not robust enough for a direct comparison between residential and commercial greywater. Experience gained in this experiment will be of importance in any future studies embarked upon, as are recommended below.

4.1.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for further work include a larger microbial water quality study, that also assesses environmental indicators such as pH, trace elements, C, N, P in soils, and emerging organic contaminants from household products, after continued and repeated irrigation with greywater. Further studies to test greywater samples for levels of other pathogens mentioned within the Southern Australian guidelines (Table 2) is also recommended.

It would also be of interest to be able to compare eco-friendly only product use with 'normal' household product only uses, with no mixing of the two. This will enable researchers to look at the effects of products with and without antimicrobial properties, and the effects of purported environmentally friendly products vs those with no claim of being environmentally friendly products.

ACKNOWLEDGEMENTS

This research project was a joint venture between BRANZ and ESR, we would like to acknowledge the funding from the Building Research Levy and the ESR Strategic Science Investment Fund, for making this research possible. Special thanks also go to Izzy Alderton and from ESR for her assistance with sample collection, laboratory analysis and testing. Thanks also to Maria J Gutierrez-Gines and Jacqui Horswell for their valuable insight and advice during the project. We are grateful to the property owners that allowed us to sample their greywater, who equally made this research possible. Further thanks go to IDEXX for providing the *Pseudolert* ® test kits for trial.

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