Study Report

SR420 [2019]

Microbial water quality of commercial and residential greywater sources

Amber Garnett

1222 Moonshine Rd
RD1, Porirua 5381
Private Bag 50 908
Porirua 5240
New Zealand
branz.nz

Funded from the
Building Research Levy

Science for Communities

The work reported here was jointly funded by BRANZ from the
Building Research Levy and by ESR from the Strategic Science Investment Fund.

ISSN: 1179-6197

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 Vikki Ambrose for sample design and for providing the results to this report and to Izzy Alderton, Seinalyn Villanueva and Charlotte Sitz for 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 who allowed us to sample their greywater who equally made this research possible. Further thanks go to IDEXX for providing the Pseudalert test kits for trial.

Microbial water quality of commercial and residential greywater sources

BRANZ Study Report SR420

Author

Amber Garnett

Reference

Garnett, A. (2019). *Microbial water quality of commercial and residential greywater sources*. BRANZ Study Report SR40. Judgeford, New Zealand: BRANZ Ltd.

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 per day) of residential water demand is water that is available for reuse. If reused, 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 property owners and water service providers. Using alternative water sources has the potential to reduce network demand, increase resilience and 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 reuse 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 reuse 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.

This study seeks to expand on previous research by assessing microbial water quality from a range of greywater sources, including greywater from residential and commercial properties. Taken weekly over 6 months, greywater samples were tested for *Escherichia coli (E. coli)* and *Pseudomonas aeruginosa (P. aeruginosa)* and compared to international greywater reuse guidelines.

Keywords

Greywater, reuse, water, recycling, residential, commercial, human health, guidelines

Contents

Figures

Tables

Glossary

cfu	Colony-forming units.
city council	City councils in New Zealand have the same function as district councils but serve a population of over 50,000.
council-controlled organisation	Any organisation in which one or more local authorities owns or controls 50% or more of the voting rights or has the right to appoint 50% or more of the directors, trustees and so on.
district council	District councils in New Zealand have the same function as city councils but serve a population of less than 50,000.
greywater	Untreated wastewater from a household or business. Toilet water and all water derived from kitchens is excluded. Toilet water is considered to be blackwater, and wastewater from kitchen sinks typically has a high organic waste content.
greywater recycling	Where the resource is broken down into raw materials that are reused. Generally, greywater recycling involves water treatment.
greywater reuse	Reusing a resource again either in the same role or in a new role. Generally, greywater reuse does not involve treatment.
MPN	Most probable number.
regional council	A regional council is one type of local authority. Regional councils' responsibilities include: • managing the effects of using freshwater, land, air and coastal waters • developing regional policy statements and the issuing of consents • managing rivers, mitigating soil erosion and flood control • regional emergency management and civil defence preparedness • regional land transport planning and contracting passenger services • harbour navigation and safety, oil spills and other marine pollution. Some district and city councils also have the powers of regional councils. These are referred to as unitary authorities.
territorial authority	This is a type of local authority. They are unitary authorities, city councils or district councils, and there are no differences in the way they operate. Territorial authorities' responsibilities include: • the provision of local infrastructure, including water, sewerage, stormwater and roads • environmental safety and health • district emergency management and civil defence preparedness • building control • public health inspections and other environmental health matters • controlling the effects of land use (including hazardous substances, natural hazards and indigenous biodiversity) • noise control • the effects of activities on the surface of lakes and rivers.
unitary authority	A unitary authority is a territorial authority that has the responsibilities, duties and powers of a regional council conferred on it. This is either by the provisions of any Act or by an Order in Council giving effect to a reorganisation scheme. There are six unitary authorities in New Zealand: Auckland, Nelson City, Gisborne District, Marlborough District, Tasman District and Chatham Islands Councils.

1. Introduction

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 reuse. Greywater is increasingly being recognised as a potential alternative source of water for non-potable end uses in residential and commercial properties.

At present, there are few areas of New Zealand that practise wide-scale greywater reuse, where the definition of reuse is to use a resource again, either in the same role or in a new role, as opposed to recycling, where the resource is broken down into raw materials that are used to make new items. In the Kapiti Coast area, for example, it has been reported that 68% or 160 litres per person per day (L/P/D) of residential water use is potential greywater that could be reused (Kapiti Coast District Council, 2008). If reused, this would represent a large proportion of a household's daily water use that would not need to be sourced from the reticulated network. This represents potential benefits for property owners and water service providers.

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, 2018).

Given the increase in water shortages 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 reuse that require more research. Bint & Jaques (2017) identified waterborne disease, water quality and risk to human health to be perceived barriers to greywater reuse in New Zealand.

The aim of this research is to expand on current research by assessing the microbial water quality from a range of greywater sources in both residential and commercial buildings. Consideration is also given to how councils across New Zealand (both regional and territorial authorities) view greywater reuse.

1.1 What is greywater?

There is no national guideline for greywater reuse in New Zealand. Therefore, multiple definitions can exist for greywater reuse and recycling. The standard for on-site domestic wastewater management (AS/NZS 1547:2012 *On-site domestic wastewater management*) defines greywater as "the domestic wastes from a bath, shower, basin, laundry and kitchen, but excluding toilet and urinal wastes which are described as black water". In practice, kitchen wastewater is generally excluded from new greywater installations because it carries fat and grease that can block pipes (Kapiti Coast District Council, 2008). Contamination such as *Campylobacter* bacteria from preparing raw meat for cooking may also be present.

Different categories of greywater are sometimes stipulated – for example, definitions can distinguish between 'light greywater', which is derived from showers, baths and hand basins, and 'heavy greywater', which is derived from washing machines and kitchen sinks and dishwashers (Gisborne District Council, 2012). Further, the Kapiti

Coast District Council do not allow laundry wastewater to be reused due to the use of household chemicals (Kapiti Coast District Council, 2017).

For the purposes of this study, greywater has been defined as untreated wastewater from a household or business. Toilet water and all water derived from kitchens has been excluded.

Figure 1 is a simplified illustration of a greywater recycling system in a residential building. Wastewater from the hand basin, bath tub and shower can be reused for purposes such as toilet flushing, subsurface garden irrigation (but is not recommended for use on vegetable gardens) and exterior cleaning, reducing the impact on the wastewater network by 150 L. End uses such as wastewater from the kitchen sink and washing machine can be directly discharged into the wastewater network as with traditional residential wastewater systems.

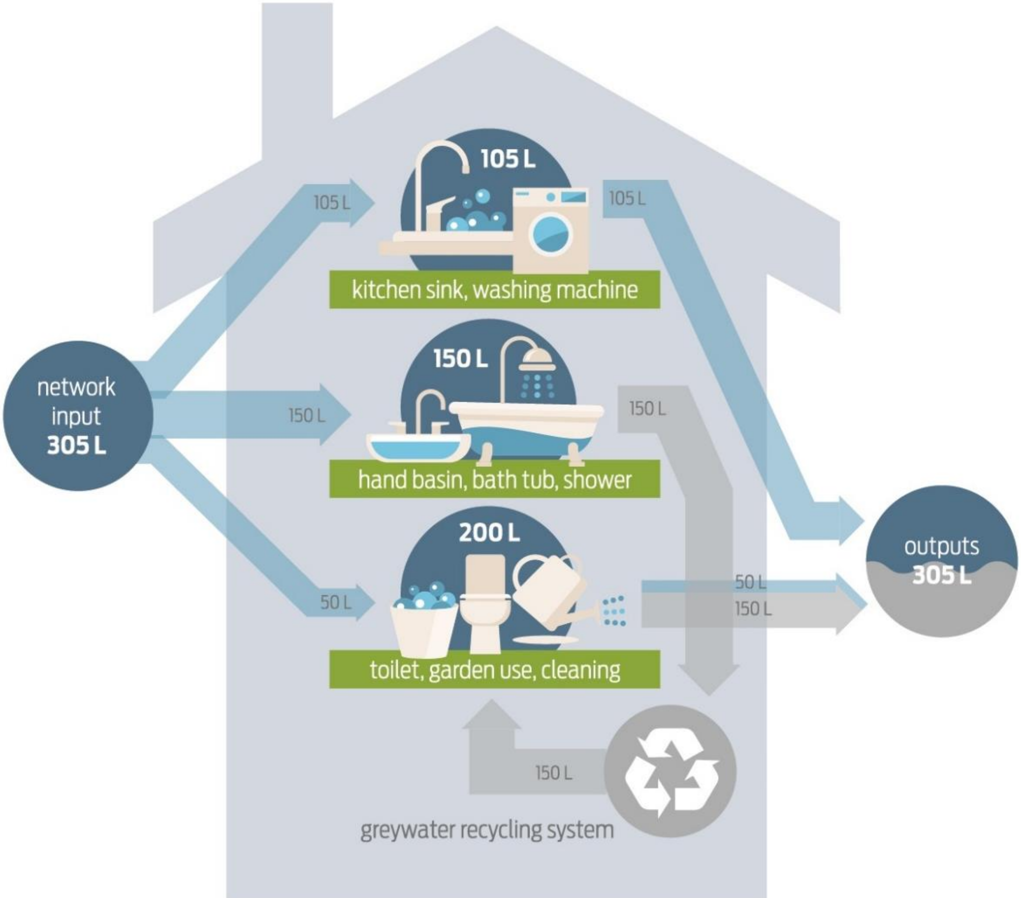

Figure 1. Simplified illustration of a greywater system in a residential building.

1.2 Greywater composition

It is critical to realise from the outset that the quality of greywater can vary considerably depending on its source. There are two prominent threats of potential contamination (Warner, 2006):

- Compounds that are found in household chemicals and products – these can include detergents, bleaches, dyes and softeners.
- Pathogenic micro-organisms found in transmission routes – for example, groundwater infiltration and aerosol inhalation.

The composition (and associated health risk) of greywater is therefore dependent on both the source and installation of the systems and occupant lifestyle and customs (Warner, 2006; Rose et al., 1991). For example, Rose et al. (1991) found that, in households with young children, greywater from all sources was significantly higher in faecal coliforms than households with no young children.

In general, it is reported that greywater has lower concentrations of micro-organisms and some nutrients (such as phosphorous and nitrogen) than combined wastewater. However, the concentration of phosphorous, organic pollutants and heavy metals are reportedly the same (Warner, 2006).

Table 1 demonstrates the potential bacterial considerations and constituents of greywater derived from bathrooms, laundries and kitchens in accordance with the greywater guidelines for residential properties in the city of Canberra (ACT, 2004). According to these guidelines, bacteria numbers are reportedly higher in shower and bath water than in laundry water samples. It is not suggested to reuse kitchen greywater as it can promote the growth of harmful micro-organisms.

Table 1. Greywater sources and potential constituents (ACT, 2004).

Source	Suitable for reuse?	Bacterial considerations	Potential constituents
Bathroom **(shower and basin)**	Yes	Bacteria numbers can be high in shower and bath water (especially if there are young people or people who suffer gastrointestinal illness). Greywater from basins is more polluted but is lower in volume.	Soap, shampoo, hair dye, toothpaste, cleaning chemicals
Laundry **(washing machine)**	Yes	Bacteria numbers in the laundry are not usually high, except when nappies are washed.	Soap, salt, sediment, organic material
Kitchen **(sink)**	No	Can promote the growth of micro-organisms and may solidify. May contain harmful bacteria	Food particles, oil, fat, other waste

1.3 Greywater volumes

1.3.1 Residential buildings

Only 19% of councils implement universal water metering on residential properties (Water New Zealand, 2017), therefore it is unclear at the national level how much water a residential home uses on average. However, a 2007 study of 12 homes on the Kapiti Coast found that, over an 8-month period, the average portion of a household's water use that was non-potable was 50%[1] (Heinrich, 2007). This represents high-quality drinking water that could potentially be reused for uses such as irrigation and toilet flushing that perhaps don't need such a high-quality source. Referring to Figure 2, it can be seen that, in winter, the average household water use used for irrigation was 9%, but in summer this more than doubled and accounted for 22% of households' water use. Therefore, reusing greywater for outdoor irrigation could have positive benefits for water supply in a season where water shortages and water restrictions are commonplace across the country.

[1] Note that 'tap' was not included in this calculation as some of this water would be derived from the kitchen, and kitchen water is excluded from the definition of greywater in this report.

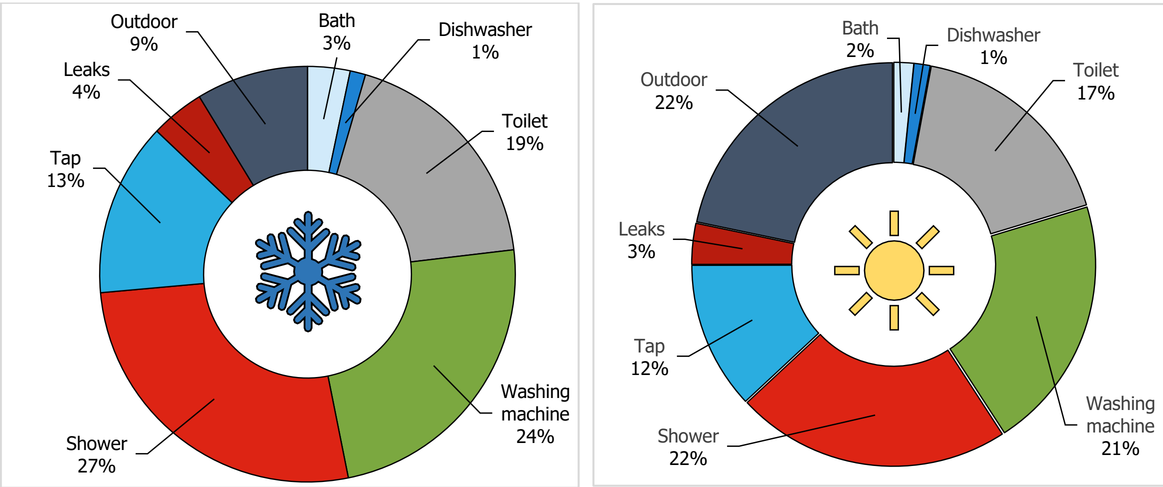

Figure 2. Comparison of the household water use of 12 homes across a winter (left) and summer (right) monitoring period (Heinrich, 2007).

To give an indication of the volumes of water being discussed for residential properties, the same data is displayed in Figure 3 and shows the volume of potential greywater generated, the volume of potential reuse and the excess volume to the wastewater network (assuming this greywater is reused).[2]

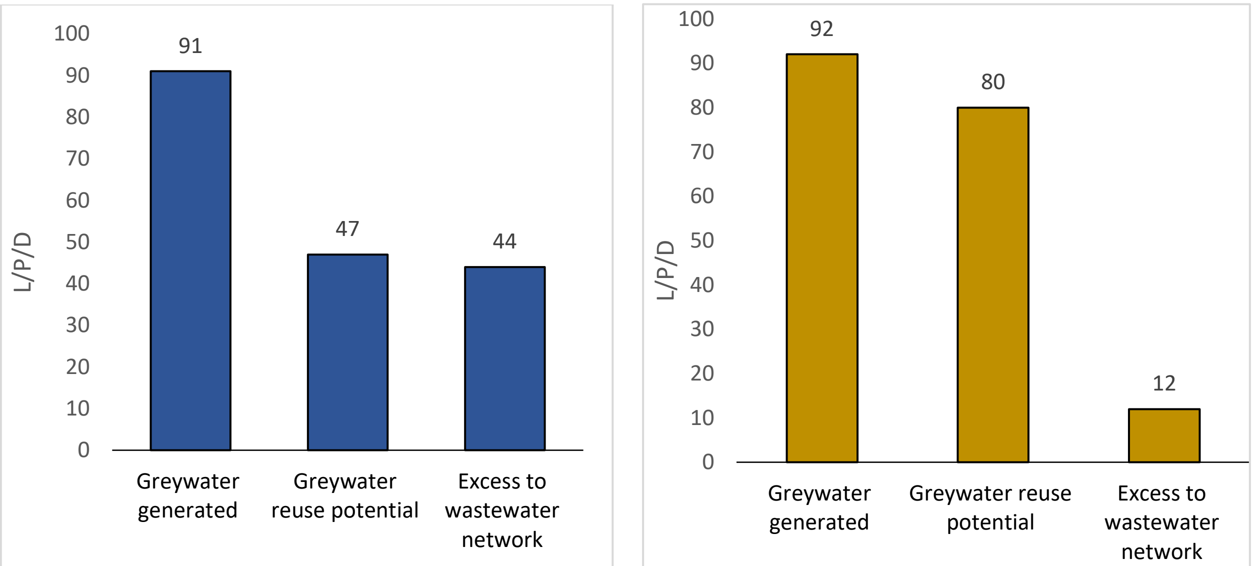

Figure 3. A comparison of the volume of greywater generated, the reuse potential and the estimated excess to the wastewater network for 12 homes across winter (left) and summer (right).

As in Figure 2, for the winter monitoring period (left), the total average household water use of 91 L/P/D is generated greywater. Assuming that all of this greywater could fully be reused, there is a potential 47 L/P/D that could be substituted from the reticulated network.

[2] This is a best-case scenario as greywater is not recommended to be stored so actual reuse volumes are potentially lower depending on the variation between households.

As discussed, in summer, the average irrigation requirement more than doubled (Figure 2). In terms of volumes of potential greywater reuse during summer, this increases to 80 L/P/D to reflect this increased irrigation demand.

1.3.2 Commercial buildings

In relation to commercial buildings, only a small number of water use studies are available. Figure 4, using percentages from the Australian water efficiency guide for office and public buildings (Quinn et al., 2006, p. 5), shows the main water uses in offices are for domestic amenities (toilets, kitchenettes, showers), air-conditioning and leakage within the building. Cooling water, irrigation and toilet flushing could all potentially be substituted by non-potable water such as greywater or rainwater.

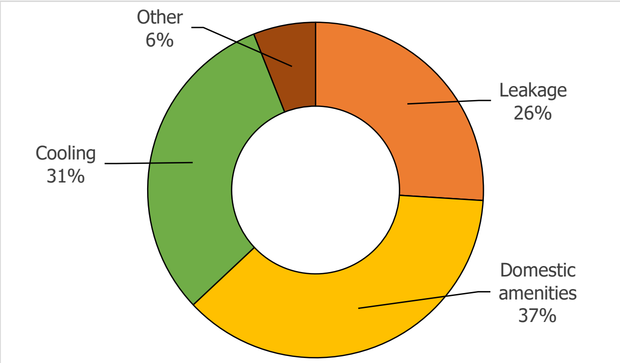

Figure 4. An example of commercial building water use (Quinn et al., 2006).

1.4 Potential benefits of greywater reuse

Greywater reuse can have a range of benefits for both homeowners and water service providers if implemented and managed correctly (Bint & Jaques, 2017; Casanova, Gerba & Karpiscak, 2001).

Potential benefits can include:

- reducing the volume of wastewater to be treated (which has financial and environmental benefits)
- positive cost-benefits of greywater reuse for homeowners (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 (such as during water restrictions).

2. Legislation and legal requirements

The provision of urban water services in New Zealand is mandated by complex statutory frameworks. Water service providers in New Zealand are responsible for the provision of drinking water, as well as wastewater and stormwater disposal, commonly referred to as the 'three waters'. There are 67 local authorities tasked with provision of the three waters in New Zealand. These authorities have the challenge of managing peak water demands while balancing the social, economic and environmental requirements and impacts. Figure 5 shows those authorities that are responsible for water provision

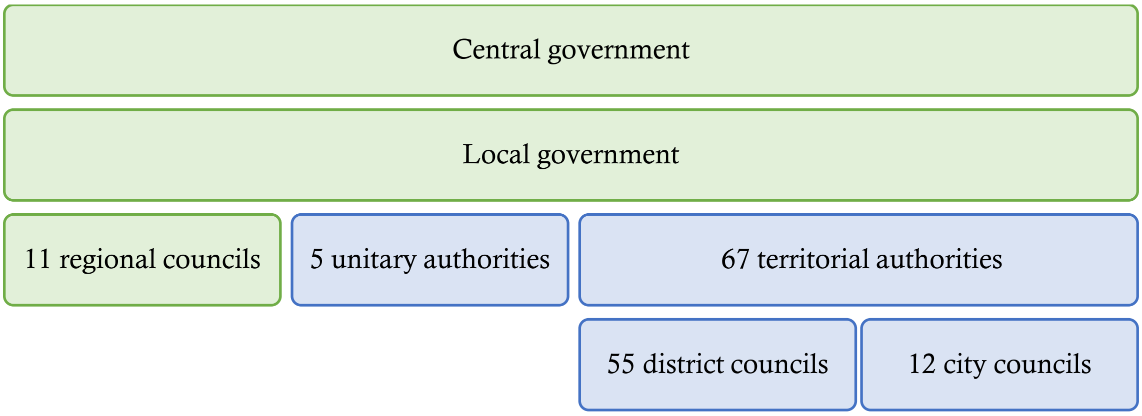

Figure 5. Hierarchy of government in New Zealand. Blue indicates those responsible for water service provision.

There is no national legislation or specific national guidelines around greywater reuse. Rules are set by local authorities. Their attitudes and requirements vary enormously around New Zealand. There are several pieces of legislation and organisations that must provide approval for the installation and maintenance of systems as well as the discharge of wastewater. Depending on the proposed system and the area of jurisdiction, the process can vary significantly. The disposal of greywater using an on-site wastewater treatment system would be covered the same as other on-site wastewater treatment systems.

Prominent legislation relating to the reuse of greywater can be seen in Figure 6. The Building Act, Health Act and Resource Management Act (RMA) are the prominent pieces of legislations that apply to on-site wastewater systems (including greywater). The Building Code has specific requirements covering design and installation of on-site systems. The requirements to meet the Building Code specifications are granted consent by the 67 territorial authorities across New Zealand.

In contrast to the Building Code, the Health Act has powers that can be invoked when an existing system is becoming or has been recognised to be a public health risk. Requirements under the Health Act are also monitored by territorial authorities across New Zealand.

The white area of Figure 6 relates to the powers, duties and functions of territorial authorities, while the coloured areas are powers, duties and functions of regional councils.

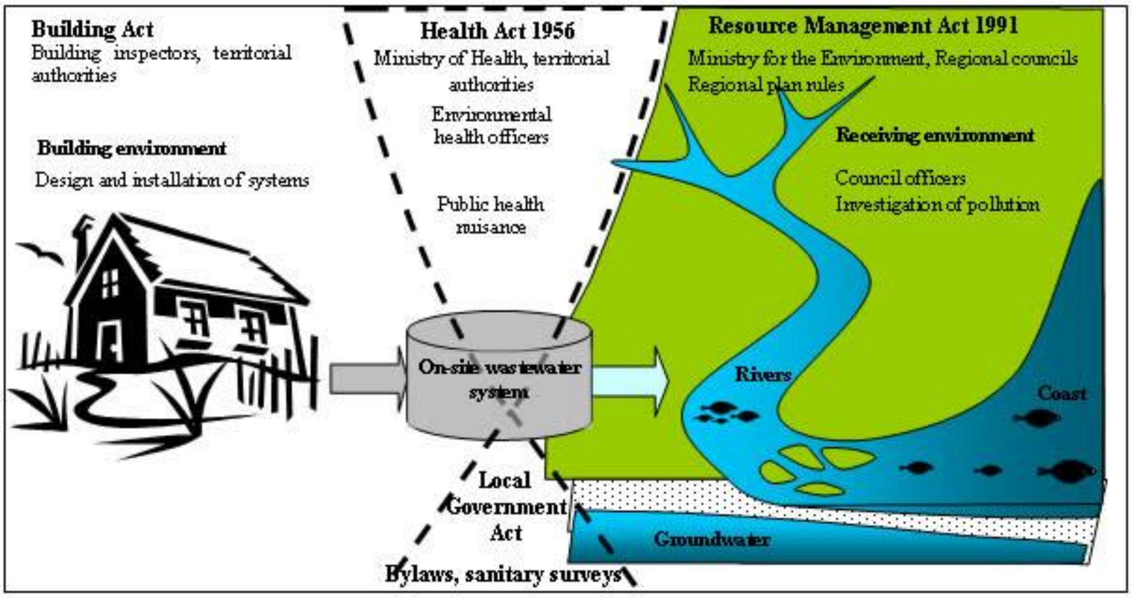

Figure 6. Summary of the various controlling legislation for on-site wastewater management (Ministry for the Environment, 2008).

2.1 Council perspectives on greywater

2.1.1 Survey methodology

There are 67 territorial authorities in New Zealand that are responsible for water service provision (Figure 5). With no national guidance on greywater reuse for residential and commercial property owners, we wanted to investigate how these individual councils view and provide guidance on greywater systems across New Zealand.

The survey was adapted, with permission, from a previous greywater survey conducted in 2011 for the New Zealand Land Treatment Collective (McCormack, 2011). Questions from the original survey were adapted slightly, but comparisons from 2011 and 2018 results are compared, where applicable, to see if viewpoints have altered over the 7-year period (see Appendix A).

We asked each of the councils (district, regional and unitary authorities) the following four questions:

- Is on-site greywater reuse a permitted activity?
- If so, how many houses have greywater systems?
- If not a permitted activity, how would a request be dealt with?
- What limitations are there to increased uptake?

2.1.2 Survey results and discussion

Is on-site greywater reuse a permitted activity?

In lieu of a national guideline, we wanted to know how the different jurisdictions around the country categorise greywater reuse as either a permitted activity or a non-permitted activity. A permitted activity under the RMA is defined as an activity that can be carried out without the need for resource consent as long as it complies with any requirements, conditions and permissions specified in the RMA regulations and in any applicable plans or proposed plans (Environment Foundation, 2018).

Below is an example of the responses for all councils within Horizons Regional Council jurisdiction (see Appendix A for all other councils). Figure 7 demonstrates the variability in responses between territorial authorities (district and city councils in this instance) but also in relation to the guidance from Horizons Regional Council. In this instance, Palmerston North City Council, Horowhenua District Council and rural properties in the Tararua District Council jurisdiction permit the reuse of greywater while Manawatu District Council and Ruapehu District Council have no policy relating to greywater reuse. In contrast, Horizons Regional Council does not consider greywater reuse to be a permitted activity, and greywater is not mentioned explicitly in their One Plan document.

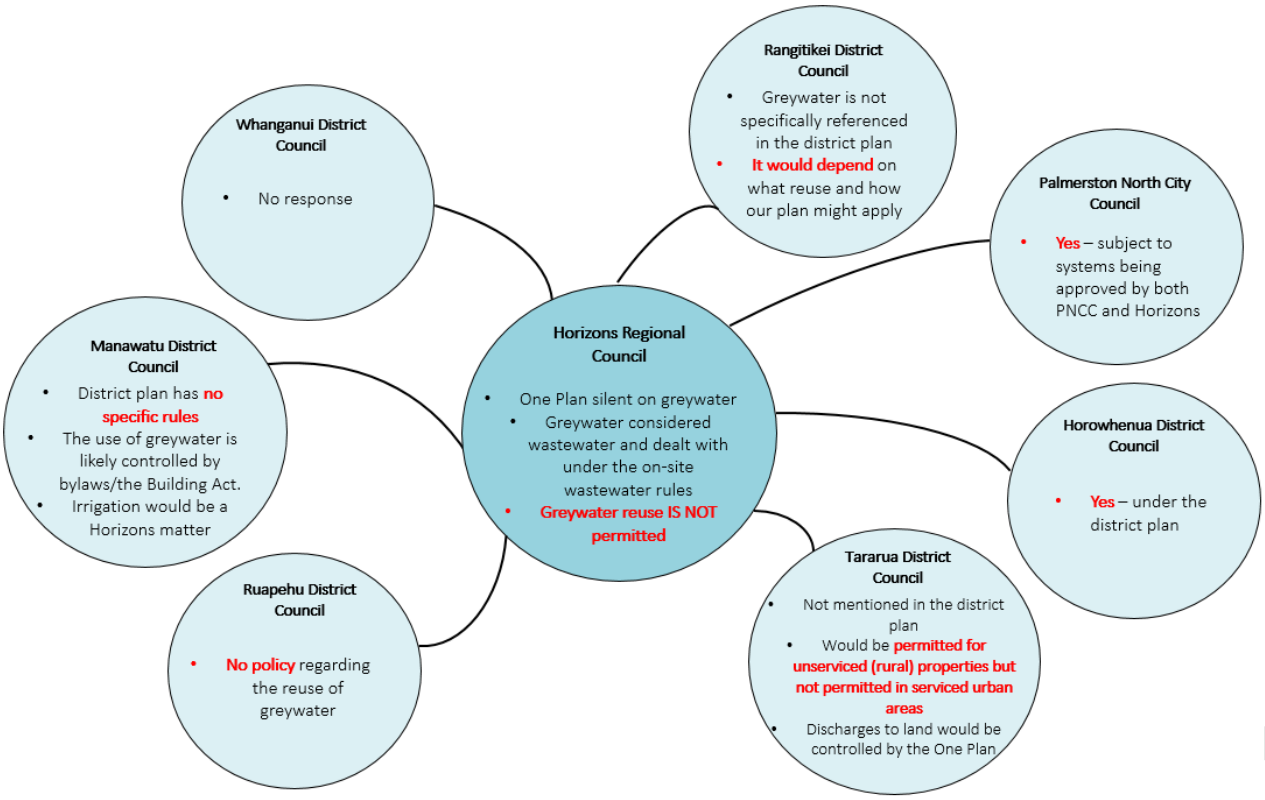

Figure 7. Are greywater reuse systems a permitted activity? Views of councils within the Horizons Regional Council jurisdiction.

Across all council responses, it was observed that there is wide variability in greywater guidance across New Zealand and also, as Figure 7 demonstrates, amongst councils within the same region.

How many houses have greywater systems?

It is difficult to gain an understanding of the number of residential and commercial buildings in New Zealand that have active greywater systems. Where greywater reuse is a permitted activity, the installation of these systems is not recorded by council. Where a consent is granted as part of an on-site wastewater treatment system, greywater is not always distinguished, thus amplifying the difficulties in quantifying the number of properties in which the systems operate.

This is reflected in the responses from councils when we asked how many systems existed in their jurisdictions. Of the councils that responded (69%), 28 did not know or did not record this information, seven estimated there were no systems, seven estimates under 20 systems in their jurisdictions and one (Kapiti Coast District Council) recorded more than 50 systems in operation.

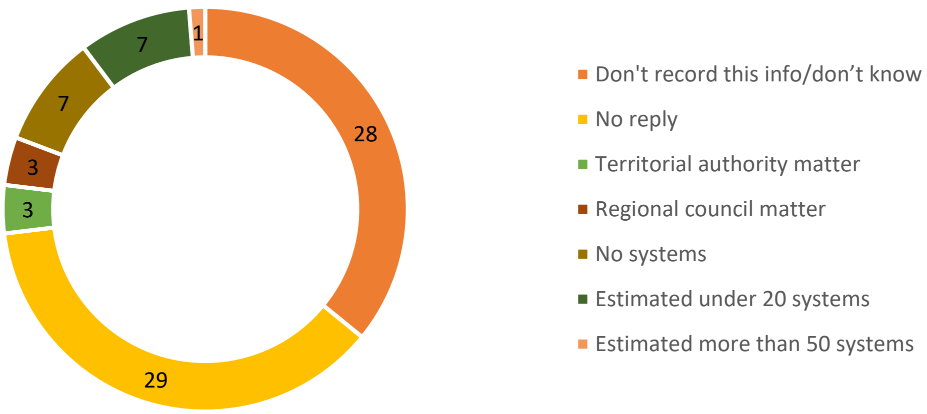

Figure 8. Survey response: How many houses have greywater systems?

Case study: Encouraging greywater reuse on the Kapiti Coast

An increased outdoor water use demand in summer was putting pressure on water supply, so in 2008, Kapiti Coast District Council made a change to its district plan that required all new dwellings connected to the town water supply to reduce their peak reticulated water use by 30% (Kapiti Coast District Council, 2017) while:

- protecting reticulated water supply and households from cross-contamination
- preventing unacceptable risk to the receiving environment (including human health).

In line with this, in 2009, Kapiti Coast District Council made it compulsory for all new residential dwellings to have an alternative non-drinkable water supply for outdoor, washing machine and toilet flushing use (Kapiti Coast District Council, 2017). There were two proposed avenues to achieve this:

- A 4,000 litre rainwater storage solution connecting to toilets and outdoor taps and a greywater diversion device – the preferred option.
- A 10,000 litre rainwater storage solution connecting to toilets and outdoor taps.

Kapiti Coast District Council is thus far the only documented council in New Zealand to actively encourage the uptake of greywater reuse systems. As such, it has the best understanding of how many properties have the systems and has the most systems of all the councils surveyed.

How are requests dealt with by councils?

If greywater reuse is not a permitted activity, we wanted to know how a request to install one of these systems would be dealt with by councils across the country. There was a wide range of responses (the most common are in bold) including:

- **would need a resource consent through the regional council**
- **would process the application through a building consent**

- process would be the same as any consent – would look to the on-site domestic wastewater management standard (AS/NZS 1547:2012) for as much guidance as possible
- on a case-by-case basis
- treated as an on-site wastewater system
- if not permitted, it would need to treat waste to a high standard
- system would be assessed on its merits and recommendations from anyone appropriately qualified
- regional council matter
- would require seeing the design and ongoing monitoring programme
- administer regional council rules – would approve considering it met Building Code and RMA rules.

Overall, there appeared to be some overlap between territorial authorities and regional councils, with the two quite often referring to the other when discussing who would be responsible for dealing with a greywater consent. A similar conclusion was drawn in the 2011 survey, where it was observed that there was considerable inconsistency between regional and unitary councils and territorial authorities for the approval and management of greywater systems (McCormack, 2011).

Are there any limitations to increased uptake?

Given that greywater reuse systems do not appear to be widely installed throughout New Zealand, we asked all councils what the limitations to uptake of these systems were from a council perspective (Figure 9).

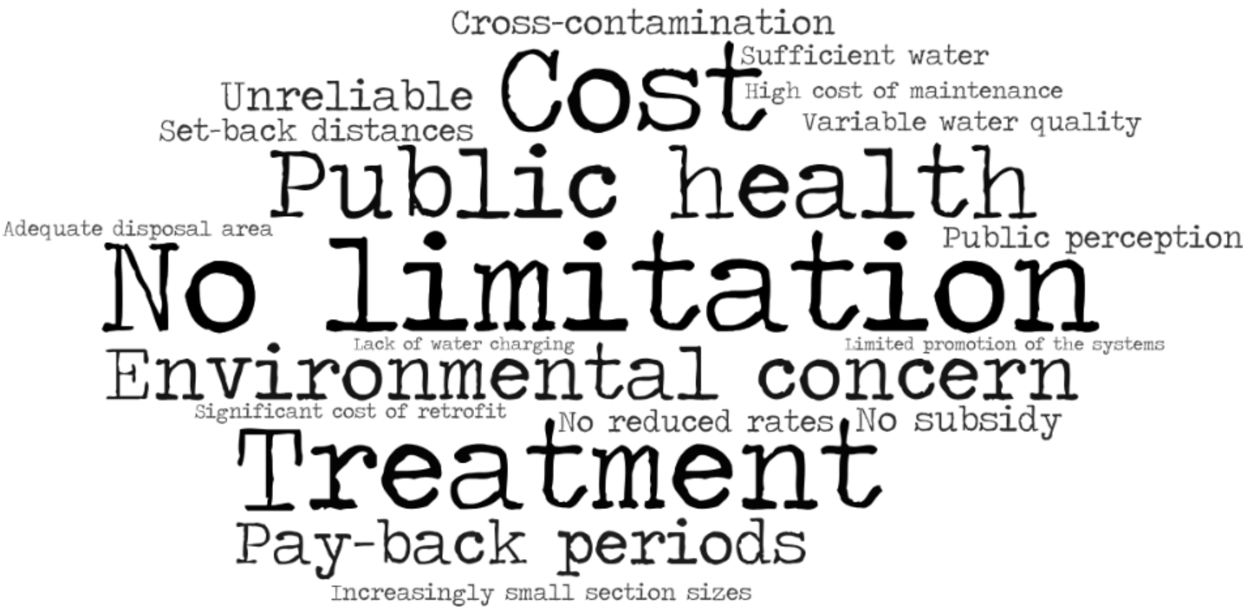

Figure 9. Word cloud of some of the limitations to uptake of greywater reuse systems from a council perspective.

Cost and environmental factors were often quoted as a limitation from a council perspective. For example, some councils did not see the need for the systems at the present time as they were not experiencing water shortages or did not have the water tariff structures to support the encouragement of the systems.

In 2014, Bint and Jaques surveyed building and construction industry representatives, and asked them "What is your primary concern with having a rainwater harvesting and/or greywater recycling system?" As can be seen in Figure 10, it was found that the largest perceived problems associated with greywater reuse systems were waterborne disease, water quality and health.

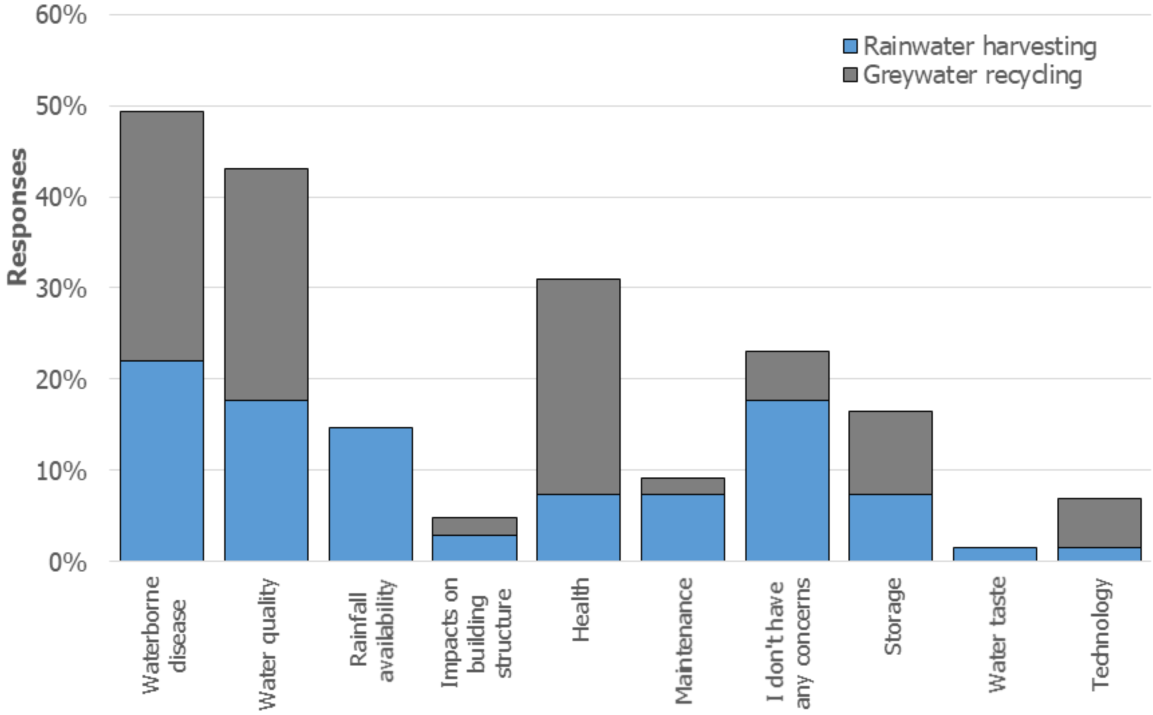

Figure 10. Primary concerns with greywater systems in 2014 (Bint & Jaques, 2017).

2.2 Performance, maintenance and compliance

In 2007, the Ministry for the Environment undertook a comprehensive review of all regional plans and bylaws related to the consent status and maintenance provisions of on-site wastewater systems (Ministry for the Environment, 2008).

While this did not differentiate greywater systems specifically, it does give an indication of how well on-site wastewater treatment systems perform and are monitored across the 16 regional councils and unitary authorities.

The review found the controls applied to on-site systems varied depending on council implementation. It was found that some regional councils require resource consent and have comprehensive information available for the public, while others permit all on-site systems through rules in their regional plans.

Where the installation of on-site systems is a permitted activity, councils are not able to recover the cost of monitoring these activities and have competing demands for limited financial resources and environmental monitoring.

As a result, councils might not have the resources to monitor activities such as discharges from on-site systems and consequently may only become involved when serious problems have occurred.

The findings of the review can be seen in Table 2, which shows only a small portion of councils monitored the performance of on-site systems or had a formal requirement for property owners to maintain their systems.

Table 2. Local government management requirements for on-site wastewater systems (Ministry for the Environment, 2008).

Council requirement	Regional councils	Territorial authorities
Regular pump-outs (compulsory)	2 (only for sensitive areas)	3 (through bylaws)
Systems maintained according to manufacturer's specifications (recommended)	2 (only for secondary systems)	-
Systems maintained on a regular basis (recommended)	9	-
No formal maintenance and inspections requirements (unless consented)	3	71

Case study: Maintenance – Far North District Council

A Far North District Council bylaw requires that all on-site wastewater systems be:

> … installed, repaired, extended, operated and maintained in a safe and sanitary manner, with no, or minimum adverse effects on the surrounding natural environment, or are a health nuisance, and in a manner that is culturally sensitive.

A survey of on-site systems in the Okiato Point area found stormwater drains to contain unacceptable concentrations of faecal coliforms and *E. coli* (Ministry for the Environment, 2008). Far North District Council responded by initiating a programme of septic tank cleaning. Post-maintenance, sampling showed a significant drop in *E. coli* and faecal coliform counts, suggesting that the high bacterial concentrations were related to a lack of maintenance.

Each month, Far North District Council sent reminder letters to property owners of systems that were due for servicing. There were also subsidies available to property owners to assist in the maintenance requirements of their on-site systems.

Having a maintenance plan and regular inspections can improve the performance of wastewater systems, which has positive impacts for the environment and human health. Unfortunately, many people do not understand or recognise the importance of managing and maintaining their on-site systems (Ministry for the Environment, 2008).

In Kapiti Coast, while uptake of greywater reuse systems is encouraged, there are no guidelines around system maintenance in the district council guideline itself. However, one of the guidelines aims is to ensure residents with a rainwater and/or greywater system understand their responsibilities in the safe use of non-drinkable water and ongoing maintenance of the systems (Kapiti Coast District Council, 2017).

3. Microbial water quality of greywater

One of the challenges to increased uptake of greywater reuse systems in New Zealand is the lack of consistent guidance and the perceived risk to human health. Referring to Figure 10, the three largest perceived barriers to increased uptake by survey respondents from the building and construction industries were waterborne disease, water quality and health concerns (Bint & Jaques, 2017). As a result of the survey results, the microbial water quality of a single commercial greywater building was sampled before and after filtration and treatment over a 3-month period.

Overall, it was concluded that greywater quality was better than anticipated. Low levels of *E. coli* were detected in only three of the pre-filtration and treatment samples. Post-filtration and treatment, no *E. coli* or other microbial detections occurred (Table 3).

Table 3. Microbiology in monthly greywater samples from a commercial building (Bint, 2017).

B1	*Escherichia coli* MPN/100mL	*Campylobacter* spp. MPN/100mL	*Salmonella* spp. MPN/100mL
Guideline limit	1	-	-
Detection limit	1	2	2
Sampled range	0–2,400	0	0
Samples detected	3/24	0/24	0/24

The recommendation from this particular study was that more sampling from commercial and residential buildings was required to make the conclusion more representative. This research is intended to build upon the water quality monitoring conducted by Siggins and Cressey (2017) as part of the rainwater harvesting and greywater recycling research programme (Bint, 2017).

3.1 Methodology

3.1.1 Sample selection

Greywater from several sources in both residential and commercial properties were sampled weekly, over a period of 2–6 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 4 assigns each of the residential and commercial properties sampled with a unique identifier to ensure anonymity.

Table 4. 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	1	14	12
Laundry sample					5		6	9		

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. Of the eight residential properties sampled, 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. From the shower, the water runs down the drain and into pipes that converge into a gully trap before going out to a greywater tank to be filtered and then out onto the property's land via a dispersal field. A separate blackwater 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 the blackwater and greywater systems are gravity fed.

In property 3, rainwater is captured, stored and pumped into 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 subsurface 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.

3.1.2 Sampling protocols

Sampling protocols were developed separately for residential and commercial properties but 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. Figure 11 shows the sampling set-up in a commercial office building.

Figure 11. An example of the sampling set-up in a commercial office building.

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.

3.1.3 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 (MPN) of *E. coli* present in the 100 ml sample.

Samples were also analysed for *P. aeruginosa* using the Pseudalert testing method, also from IDEXX. *P. aeruginosa* is a pathogenic microorganism commonly found in greywater (Maimon, Friedler & Gross, 2014). It is ubiquitous in the environment, living on inert and living (i.e. human and plant tissue) matrices (Botzenhart & Döring, 1993). 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 Pseudalert tests were calculated using MPN tables incorporated in the IDEXX method. In the corresponding figures (Figure 12 through to Figure 17), results <1 MPN/100 mL are represented as 0.1 MPN/100 mL. Due to the high variability of the results, this report has chosen to display each sampling event separately instead of calculating the averages.

The upper threshold of the IDEXX method for both *E. coli* and *P. aeruginosa* is >2,419.6 MPN/100ml. The samples with results above this threshold were retested the following day after being diluted 1:100 or 1:10 respectively, and the appropriate dilution factor was applied in calculations. Having been analysed at 48 hours, some of the results of the dilutions were not accurate, and in the graphics, the original results were plotted in brown. In some other occasions, the results were higher than the threshold, even after diluted. In that case, the results will be shown as "higher than threshold".

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

4. Microbial water quality results

4.1 Residential and commercial shower samples

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

4.1.1 *E. coli*

The most probable number of *E. coli* per 100 mL can be seen in Figure 12 and ranges from <1 MPN/100 mL in properties 2, 3 and 4 to >241,960 MPN/100 mL in property 3 (with property 3 displaying the greatest variation overall). While only five samples were collected for the commercial building (property 9), the variation between samples was low, ranging from <1 MPN/100 mL to 727 MPN/100 mL. Properties 1 and 3 both have greywater systems installed.

When compared to the *E. coli* levels observed by Leonard & Kikkert (2006), all results were notably lower than their higher reported value, with properties 2, 3 and 4 having *E. coli* concentrations lower than the lowest value observed in their study.

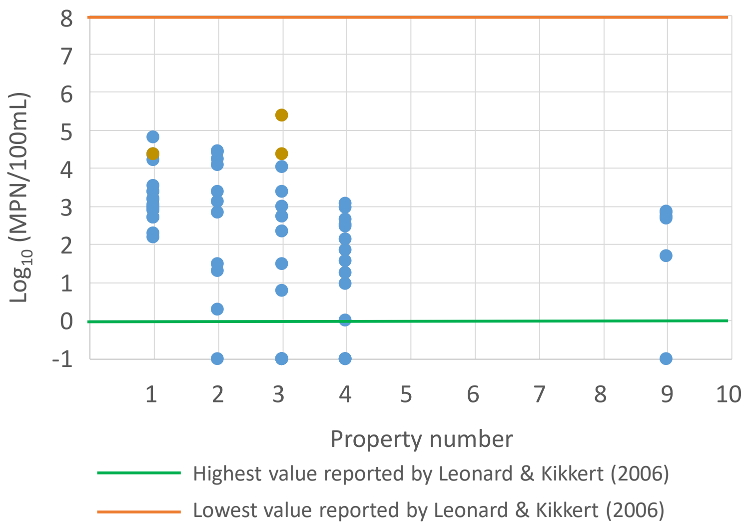

Figure 12. *E. coli* results from shower samples compared with international results. Blue dots are the results of each sampling event, brown dots represent those results that were higher than the upper threshold of the method.

4.1.2 *P. aeruginosa*

The lowest numbers of *P. aeruginosa* recorded from residential and commercial showers were <1 MPN/100 mL in properties 1, 2 and 3 and commercial property 9 (Figure 13). Property 2 was found to have the lowest and most consistent numbers of *P. aeruginosa* ranging from <1 to 6 MPN/100 mL.

The highest recorded value was from property 4, with a *P. aeruginosa* concentration higher than 24,196 MPN/100 mL (which was the upper limit of the testing[3]). Overall, the greatest variation was found in property 1, with *P. aeruginosa* ranging from <1 to 19,863 MPN/100 mL.

In relation to Benami et al. (2016) and Casanova et al. (2001), the concentrations of *P. aeruginosa* were lower than their higher reported values, and in the case of property 2, they were lower than their lower reported value for all samples tested.

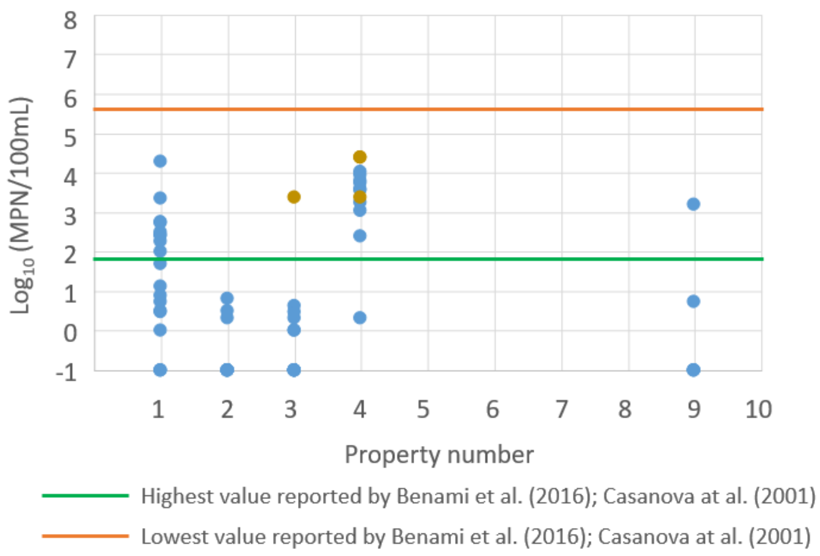

Figure 13. *P. aeruginosa* results from shower samples compared with international results. Blue dots are the results of each sampling event, brown dots represent those results that were higher than the upper threshold of the method.

4.2 Residential and commercial hand basin samples

The hand basins from six residential properties were sampled for *E. coli* and *P. aeruginosa* for between 7 and 14 weeks (see Table 4). 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 commercial property, the individual hand basin samples were combined and mixed well to give one composite sample per property per week.

4.2.1 *E. coli*

As can be seen in Figure 14, residential hand basins (properties 1–8) had *E. coli* numbers ranging from <1 MPN/100mL in properties 2, 4, 5, 6 and 7 to 547 MPN/100mL in property 2. *E. coli* concentrations in the residential hand basins were

[3] There was an unexplained issue with the dilutions on the Pseudalert counts with some high levels of *P. aeruginosa*, where the initial counts were >2,419.6 MPN/100ml (maximum count). This required further dilution to repeat the count. Results from these dilutions were sometimes negative. The initial Pseudalert 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.

consistently lower than 1 (hence giving the appearance of a single sample) with only four sampling events measuring *E. coli* concentrations greater than 1 MPN/100mL across all properties.

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 and 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 properties 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 their upper recorded values.

In relation to study conducted by Birks et al. (2004), it can be seen in Figure 14 that all samples tested fell below the higher recorded value. The lower threshold was measured at <1 MPN/100mL, which was found to be similar to the majority of samples analysed as part of this study.

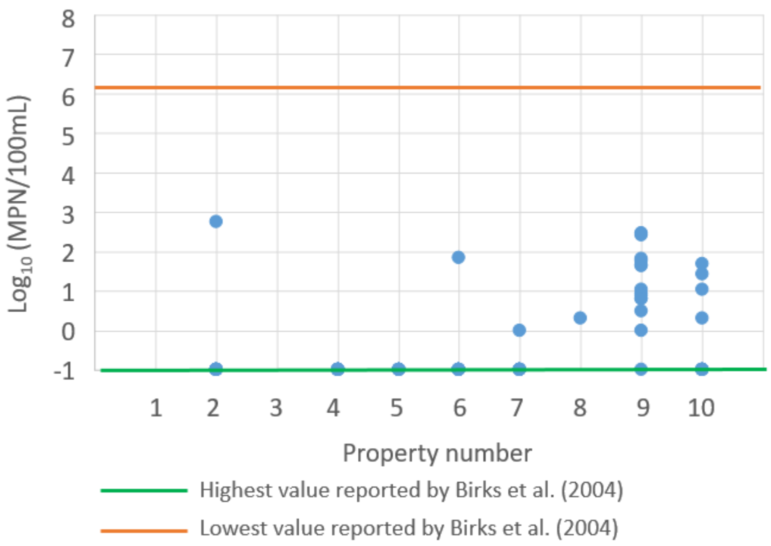

Figure 14. *E. coli* results from hand basin samples compared with international results.

4.2.2 *P. aeruginosa*

Concentrations of *P. aeruginosa* in residential and commercial hand basins ranged from <1 to >241,960 MPN/100 mL, as can be seen in Figure 15. *P. aeruginosa* levels were varied in all residential hand basin samples, with 46% of samples (23/50) testing positive for *P. aeruginosa.* Overall, 80% of the residential basin samples presented values of *P. aeruginosa* below 200 MPN/100 mL, and only 20% were above the upper threshold limit of the testing methodology (>2,419.6 MPN/100 mL).

Of the two commercial properties, property 10 had *P. aeruginosa* numbers that were more consistent with the results found in the residential properties, with 78% of the samples with numbers below 200 MPN/100 mL and 15% of samples >2,419.6 MPN/100 mL. This was probably due to the number of contributors also being more representative of a residential property.

When compared to research conducted by Benami et al. (2016), it can be seen that the majority of samples fell below their observed lowest values. Property 9 showed the greatest variation of all the properties sampled.

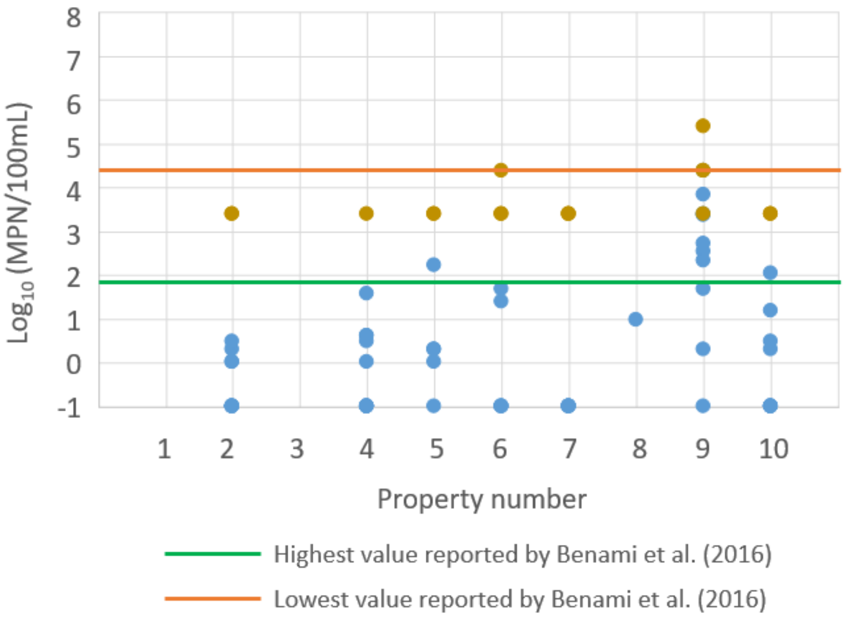

Figure 15. *P. aeruginosa* results from hand basin samples compared with international results. Blue dots are the results of each sampling event, brown dots represent those results that were higher than the upper threshold of the method.

4.3 Residential laundry samples

4.3.1 *E. coli*

Laundry samples were taken from three residential properties for between 5 and 9 weeks (see Table 4). No commercial laundries were sampled. As can be seen in Figure 16, *E. coli* concentrations in residential laundry samples (derived from washing machines) ranged from <1 to >24,196 MPN/100 mL (in property 8). Property 5 had the lowest variation, with *E. coli* concentrations ranging from <1 to 4.1 MPN/100mL. Property 7 had two positive *E. coli* numbers of 12 and 3 MPN/100 mL, with the remaining four samples at <1 MPN/100 mL. When compared with O'Toole et al. (2012), it can be seen that the *E. coli* concentrations from property 5 were lower than the lowest observed value, while properties 7 and 8 had a few sampling events above the lower threshold observed by O'Toole et al. (2012). All samples taken were below the highest value for *E. coli* observed.

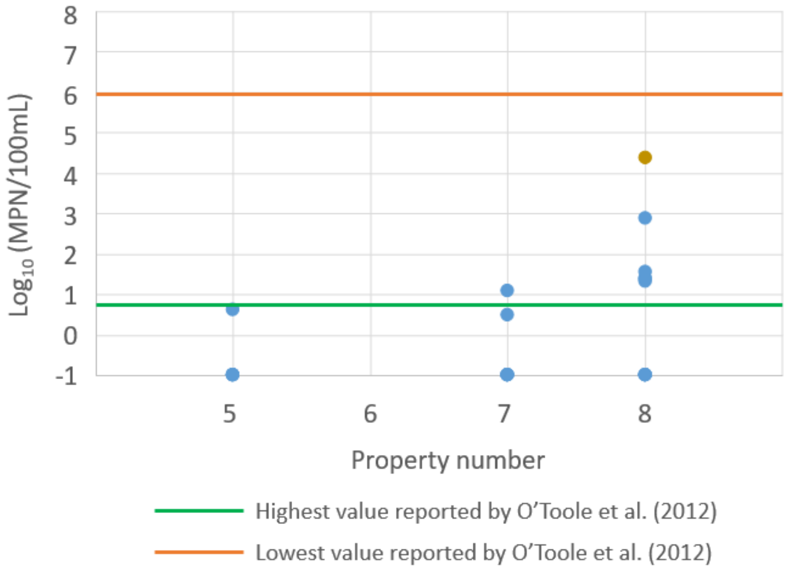

Figure 16. *E. coli* results from laundry samples compared with international results. Blue dots are the results of each sampling event, brown dots represent those results that were higher than the upper threshold of the method.

4.3.2 *P. aeruginosa*

Concentrations of *P. aeruginosa* in residential laundries ranged from <1 to >24,196 MPN/100 mL (for properties 7 and 8). There was quite a lot of observed variation between properties but also within the same property. This is demonstrated clearly for property 5, in which *P. aeruginosa* numbers range from <1 to >2,419.6 MPN/100 mL. When compared to the results from Casanova et al. (2001), it can be seen that all samples fell below their upper observed value, and about half of all samples taken fell below their lowest observed value.

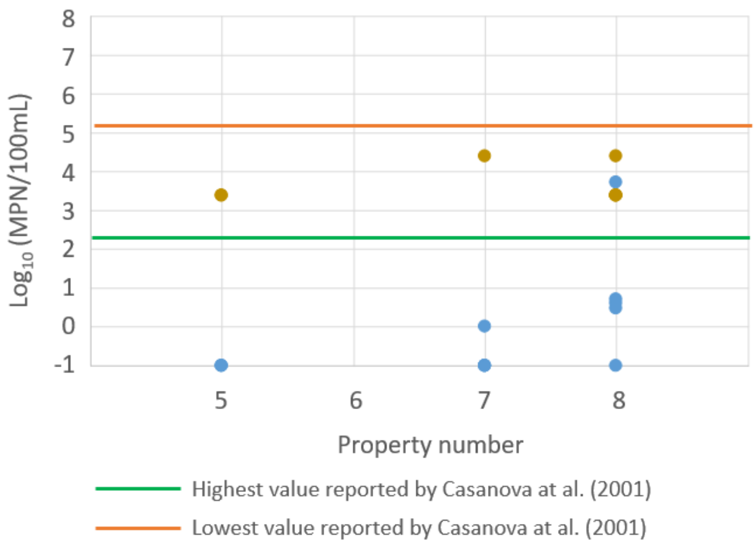

Figure 17. *P. aeruginosa* results from laundry samples compared with international results. Blue dots are the results of each sampling event, brown dots represent those results that were higher than the upper threshold of the method.

4.4 Comparison between source and end use

Property 3 has an active greywater system that irrigates greywater from the shower directly onto a dispersal field in the garden. Figure 12 and Figure 13 show the *E. coli* and *P. aeruginosa* results for property 3. At this property, the end use for greywater is a combination of surface and subsurface irrigation. Surface irrigation samples were taken and analysed for *E. coli* and *P. aeruginosa.*

4.4.1 *E. coli*

Figure 18 compares the *E. coli* concentrations in the greywater derived from the shower in property 3 and the *E. coli* concentrations after the greywater has passed through the storage tank and piping but *before* it is surface irrigated and interacts with the soil environment.

There is notable variation in the concentrations of *E. coli* found in both shower and surface irrigation samples. The largest variation was observed in sample 12, where *E. coli* ranges from 6.3 MPN/100mL in the sample derived from the shower but reaches 24,130 MPN/100 mL when it is sampled at the pipe for surface irrigation. There appears to be no clear trend with either source consistently having higher *E. coli* counts than the other.

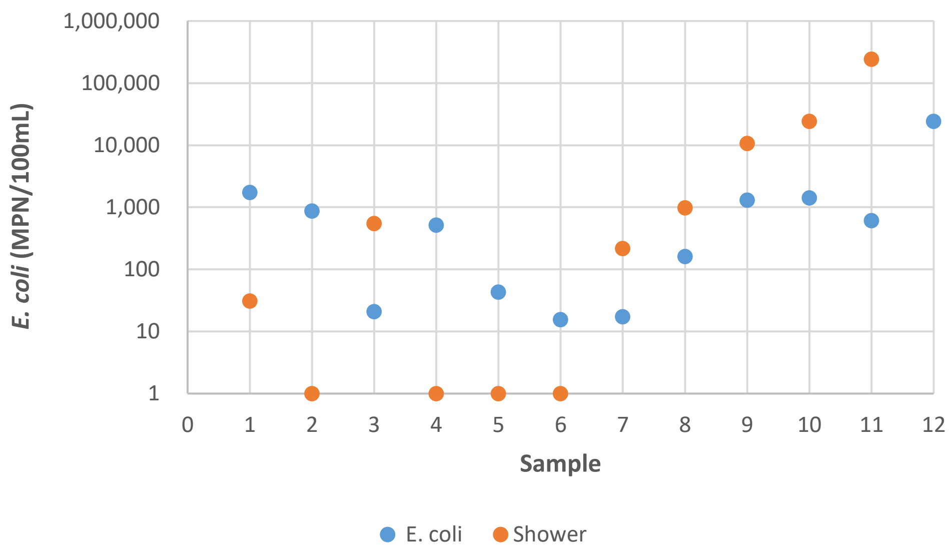

Figure 18. A comparison of *E. coli* in samples derived from the shower and pre-surface irrigation in property 3.

4.4.2 *P. aeruginosa*

Figure 19 compares the *P. aeruginosa* concentrations in the greywater derived from the shower in property 3 and the *P. aeruginosa* concentrations after the greywater has passed through the storage tank and piping but *before* it is surface irrigated and interacts with the soil environment.

For all sampling events, the most probable number of *P. aeruginosa* (per 100mL) increases significantly in the samples taken at the pipe for surface irrigation compared with the samples derived from the shower. For 9/12 samples taken, the variation ranges from <1 MPN/100mL in shower samples to the upper threshold of the testing method (>2,419.6 MPN/100 mL) in the surface irrigation samples. Sample 9 has the lowest variation between the shower and the surface irrigation sample, ranging from 2 MPN/100mL in the shower through to 8.4 MPN/100mL in the irrigation sample.

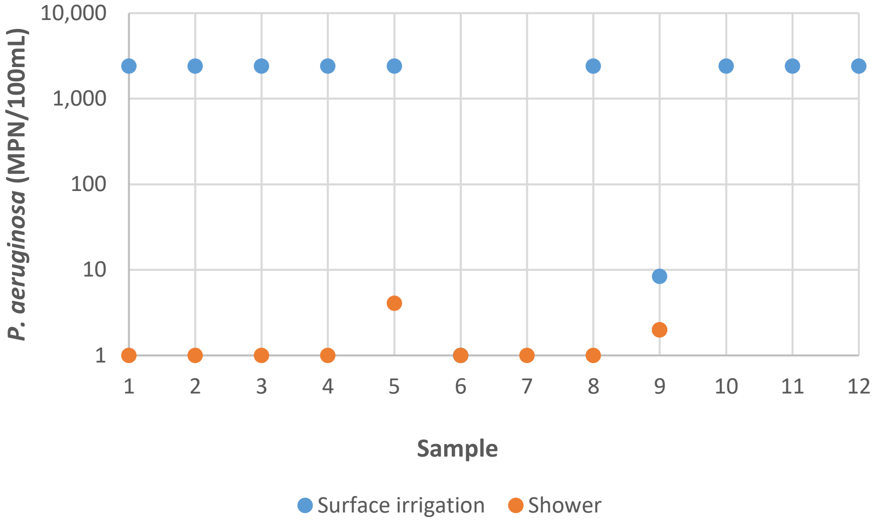

Figure 19. A comparison of *P. aeruginosa* in samples derived from the shower and pre-surface irrigation in property 3.

5. Discussion

As can be seen in Figure 12 through to Figure 17, in comparison to similar studies, neither the most probable number (MPN/100mL) of *E. coli* or *P. aeruginosa* exceeded the highest observed values for any of the three sources of greywater sampled (showers, hand basins and washing machines). *P. aeruginosa* concentrations in residential property 6 and commercial property 9 did reach the highest values observed by Benami et al. (2016) in samples derived from the hand basin. Interestingly, the lowest numbers of *P. aeruginosa* were found in residential shower samples, which is in contrast to the *E. coli* numbers (Figure 12) 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).

5.1 Comparison with overseas guidelines

5.1.1 *E. coli*

Greywater from a range of sources in both residential and commercial properties was analysed over 2–6 months (depending on the property) for both *E. coli* and *P. aeruginosa*. While there are currently no national guidelines for greywater reuse or recycling in New Zealand, the *E. coli* results from this research are compared to guideline values implemented in South Australia (DHS & EPA, 1999), as can be seen in Table 5. These guidelines are also consistent with the microbial criteria implemented in the state of Victoria's greywater guidelines (EPA Victoria, 2003).

Table 5. South Australia guidelines for reclaimed water use (DHS & EPA, 1999).

Class	Uses	Microbiological criteria *E. coli* /100 mL (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	
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	
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 South Australia guidelines and can be seen in Table 6. When compared with the *E. coli* thresholds established in the South 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 5, class A reclaimed water in South 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 (cfu/100mL) (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 were 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. According to the South Australia guidelines, it would not be suitable for garden watering or toilet flushing. Of interest, property 1 has an established greywater system that is filtered (after our sampling point) and is subsurface irrigated to a dispersal field on the property. Property 3 also has a greywater system that is used for subsurface 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 1–1.4×10^7 MPN/100 mL (sampled from various countries including New Zealand) and those of Birks and Hills (2007) at 3.9×10^5 cfu/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 6. Results compared with the categories for reuse as stipulated in the South Australia 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 stabilisation 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 (DHS & EPA, 1999).

It is worth noting that, in this study, all the hand basin and laundry samples tested were from source and before 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.

Limitations

It is important to note, however, that while 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 standard indicator organism for faecal contamination.

Therefore, while the 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.

5.1.2 *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). When compared with results of similar studies (Benami et al., 2016; Casanova et al., 2001), the *P. aeruginosa* counts from residential and commercial showers and laundry samples were below the observed thresholds. However, one residential and one commercial property had *P. aeruginosa* levels in line with the upper threshold observed by Benami et al. (2016).

5.2 Lessons learned from existing systems

Only two of the nine properties sampled had active greywater systems in use – properties 1 and 3. Both of the systems were used for exterior irrigation. Through discussion with the property owners and results of the sampling, there are some notable points to mention.

5.2.1 Product selection

Property 1 utilises a Waterflow NZ – Natural Flow Ecowaste and Sewage system. Greywater is stored in a greywater tank filtered and then dispersed to land. A separate blackwater circuit feeds into a tank that contains natural filter materials and tiger worms that process the solids. Due to the nature of this 'living system', the homeowners had to be cautious of the products used in their home – chemicals posed a risk to the system's performance. This poses an interesting question around the effect that various products have on the quality of greywater. For example, how do antibacterial products affect the microbial water quality of greywater?

5.2.2 Disposal field selection and system maintenance

Property 3 also had an operational greywater reuse system. In this instance, the greywater from shower, bath and hand basin events is stored in a 40-litre greywater tank and immediately pumped through a piping system and used for both surface and subsurface irrigation. While the surface irrigation at this property was not a vegetable garden, recommendations are to subsurface irrigate to reduce any potential exposure risk that could occur as a result of surface irrigation (Kapiti Coast District Council, 2017).

Greywater samples were obtained at three sampling points, direct from the shower head (control), during showering events (therefore also capturing products used) and at the end use where the greywater was used for surface irrigation.

Figure 18 and Figure 19 show the *E. coli* and *P. aeruginosa* counts for both the shower and garden irrigation samples, respectively. Some variation can be seen in the *E. coli* concentrations in the shower and garden irrigation samples. *E. coli* was greater in the garden sample than the shower sample for 45% of samples. The shower had greater *E. coli* results than the garden irrigation samples 55% of the time.

Given the levels are much lower from the shower than they are from the surface garden irrigation samples, a control sample of the shower water taken before showering was analysed for both *E. coli* and *P. aeruginosa* and results were <0.1 MPN/100 mL.

In samples taken where surface irrigation occurs, the levels of *P. aeruginosa* were high (>2,419.6 MPN/100 mL and unable to be diluted to obtain numbers) in all but two of the 13 samples obtained. This suggests that *P. aeruginosa* is not being introduced from the human body in this particular case but most probably being introduced into the water somewhere in the piping system itself. *P. aeruginosa* is found widely in the natural and built environment, especially in water bodies or moist environments (Mena & Gerba, 2009). *P. aeruginosa* is also commonly associated in the biofilms of water systems (Trautmann, Lepper. & Haller, 2005), which suggests that the increase in the most probable number of *P. aeruginosa* in the surface irrigation samples are caused by biofilms within the piping that transports the greywater from the shower to the garden for irrigation.

6. Conclusions and recommendations

Across 2–6 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 South Australia guidelines for reclaimed water use (DHS & EPA, 1999), most samples were consistent with class A reclaimed water (with regards to the *E. coli* concentrations). More research is needed to be conclusive and to include other pathogens such as viruses, protozoa or helminths.

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-by-case basis, but subsurface 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 properties. 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 recommended below.

Recommendations for further work include a larger microbial water quality study that also assesses environmental indicators such as pH, trace elements 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 South Australia guidelines (Table 5) are also recommended.

It would also be of interest to be able to compare ecofriendly-only product use with 'normal' household-only product use. This will enable researchers to look at the effects of products with and without antimicrobial properties and the effects of purported environmentally friendly products versus other products.

Finally, a comparison of existing greywater samples, their microbial water quality and maintenance schedules would be of interest given the high variation between shower samples and end use (surface irrigation) samples observed in the sampling of residential property 3.

References

ACT. (2004). *Greywater use: Guidelines for residential properties in Canberra.* Canberra, Australia: Australian Capital Territory.

Benami, M., Busgang, A., Gillor, O. & Gross, A. (2016). Quantification and risks associated with bacterial aerosols near domestic greywater-treatment systems. *Science of the Total Environment*, *562*, 344–352.

Bint, L. (2017). *Performance of commercial rainwater and greywater systems.* BRANZ Study Report SR383*.* Judgeford, New Zealand: BRANZ Ltd.

Bint, L., & Jaques, R. (2017). *Drivers and barriers to rainwater and greywater uptake in New Zealand.* BRANZ Study Report SR382. Judgeford, New Zealand: BRANZ Ltd.

Birks, R., Colbourne, J., Hills, S. & Hobson, R. (2004). Microbial water quality in a large inbuilding, water recycling facility. *Water Science and Technology*, *50*(2), 165–172.

Birks, R. & Hills, S. (2007). Characterisation of indicator organisms and pathogens in domestic greywater for recycling. *Environmental Monitoring and Assessment, 129*(1–3), 61–69.

Botzenhart, K. & Döring, G. (1993). Ecology and epidemiology of *Pseudomonas aeruginosa*. In M. Campa, M. Bendinelli & H. Friedman (Eds.), Pseudomonas aeruginosa *as an opportunistic pathogen* (pp. 1–18). Boston, MA: Springer

Casanova, L. M., Gerba, C. & Karpiscak, M. (2001). Chemical and microbial characterization of household graywater. *Journal of Environmental Science and Health, Part A, Toxic/Hazardous Substances & Environmental Engineering, 36*(4), 395–401.

DHS & EPA. (1999). *South Australian reclaimed water guidelines: Treated effluent.* Adelaide, Australia: Environment Protection Agency & Department of Human Services, Public and Environmental Health Service.

Environment Foundation. (2018). *Resource consents and processes*. Retrieved from http://www.environmentguide.org.nz/rma/resource-consents-and-processes/

EPA Victoria. (2003). *Guidelines for environmental management: Use of reclaimed water.* Melbourne, Australia: Environment Protection Authority Victoria.

Gisborne District Council. (2012). *Guidelines for on-site wastewater management.* Gisborne, New Zealand: Gisborne District Council.

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

Kapiti Coast District Council. (2008). *Greywater reuse risk assessment.* Kapiti Coast, New Zealand: Kapiti Coast District Council.

Kapiti Coast District Council. (2017). *Kapiti Coast rainwater and greywater code of practice guidelines.* Kapiti Coast, New Zealand: Kapiti Coast District Council.

Katukiza, A. Y., Ronteltap, M., Niwagaba, C. B., Kansiime, F. &. Lens P. N. L. 2015. Grey water characterisation and pollutant loads in an urban slum. *International Journal of Environmental Science and Technology*, *12*(2), 423–436.

Leonard, M., & Kikkert, H. (2006). *Efficacy of greywater treatment in New Zealand.* Paper presented at the New Zealand Water and Wastes Association Conference, Christchurch, New Zealand, 11–13 October.

Maimon, A., Friedler, E. & Gross, A.. (2014). Parameters affecting greywater quality and its safety for reuse. *Science of the Total Environment*, *487*, 20–25.

McCormack, L. (2011). *How to be "greywater-wise" – a literature review to aid decision making around greywater issues.* Technical Review No. 32. Christchurch, New Zealand: New Zealand Land Treatment Collective.

Mena, K. D. & Gerba, C. P. (2009). Risk assessment of *Pseudomonas aeruginosa* in water. *Reviews of Environmental Contamination and Toxicology*, *201*, 71–115.

Ministry for the Environment. (2008). *Proposed national environmental standard for on-site wastewater systems: Discussion document.* Wellington, New Zealand: Ministry for the Environment.

Ministry for the Environment. (2010). *Update of water allocation data and estimate of actual water use of consented takes 2009–10*. Wellington, New Zealand: Aqualinc Research Ltd.

O'Toole, J., Sinclair, M., Malawaraarachchi, M., Hamilton, A., Barker, F. S. & Leder, K. (2012). Microbial quality assessment of household greywater. *Water Research*, *46*(13), 4301–4313.

Quinn, R., Bannister, P., Munzinger, M., Bloomfield, C. et al. (2006). *Water efficiency guide: Office and public buildings.* Canberra, Australia: Australian Government, Department of the Environment and Heritage.

Rose, J. B., Gwo-Shing, S., Gerba, C. P. & Sinclair, N. A. (1991). Microbial quality and persistence of enteric pathogens in graywater from various household sources. *Water Resources*, *25*(1), 37–42.

Siggins, A. & Cressey, P. (2017). *Monitoring and risk assessment of rainwater and greywater*. Porirua: Institute of Environmental Science and Research (ESR).

Trautmann, M., Lepper, P. M. & Haller, M. (2005). Ecology of *Pseudomonas aeruginosa* in the intensive care unit and the evolving role of water outlets as a reservoir of the organism. *Amercian Journal of Infection Control*, *33*(Suppl 1), S41–49.

Warner, W. S. (2006). Understanding greywater treatment. In D. Butler & F. Memon (Eds.), *Water demand management* (pp. 62–81). London, UK: IWA Publishing.

Water New Zealand. (2017). *National performance review 2015–2016*. Wellington, New Zealand: Water New Zealand.

Water New Zealand. (2018). *National performance review 2016–2017*. Wellington, New Zealand: Water New Zealand.

Winward, G. P., Avery, L. M., Frazer-Williams, R. & Pidou, M. 2008. A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse. *Ecological Engineering*, *32*(2), 187–197.

Appendix A: Is greywater reuse a permitted activity?

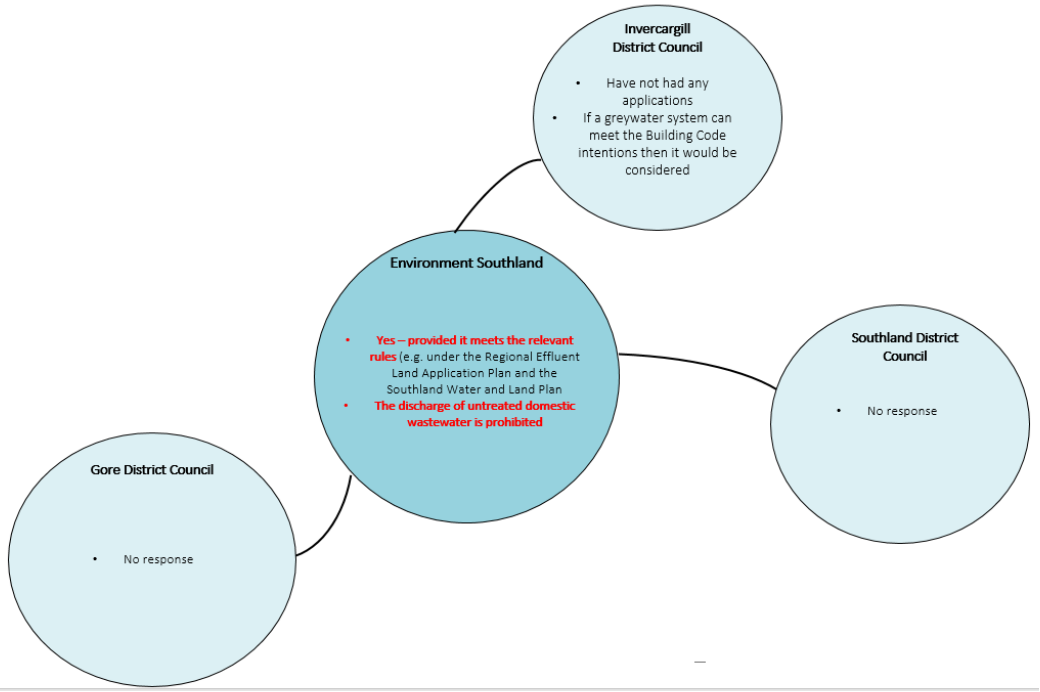

Figure 20. Are greywater reuse systems a permitted activity? Views of councils within the Environment Southland jurisdiction.

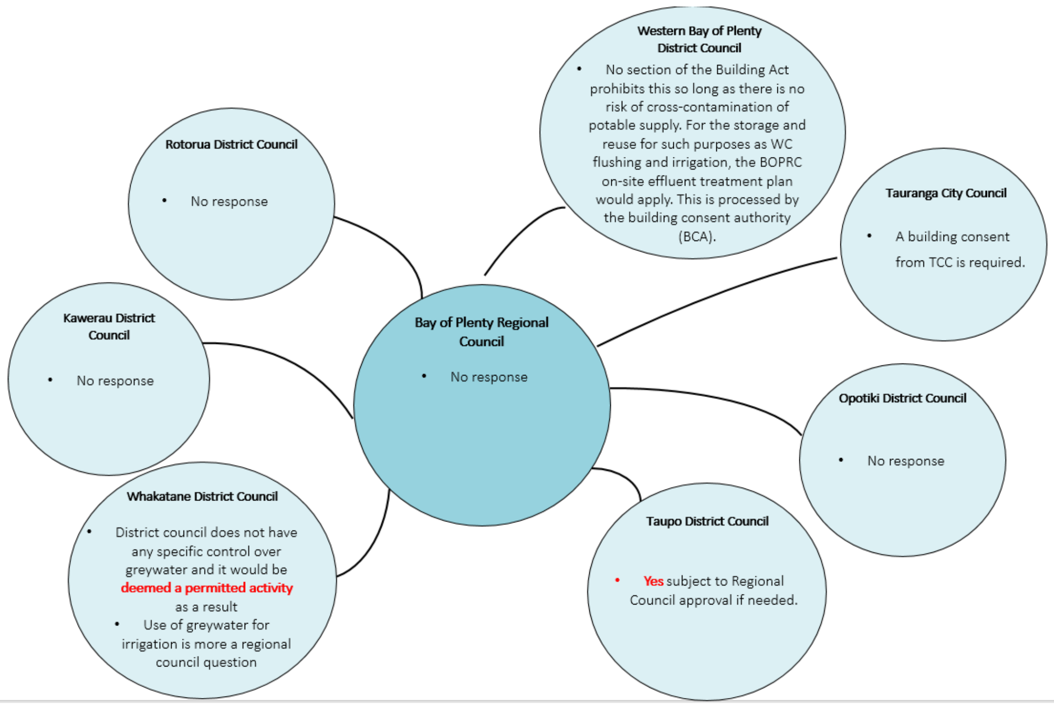

Figure 21. Are greywater reuse systems a permitted activity? Views of councils within the Bay of Plenty Regional Council jurisdiction.

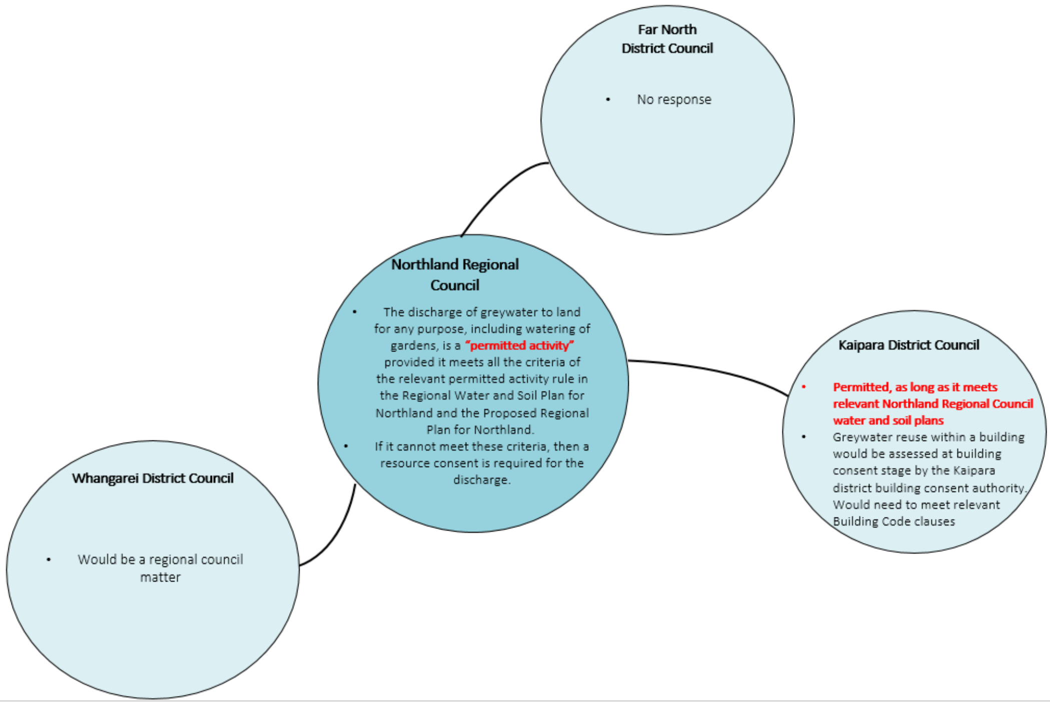

Figure 22. Are greywater reuse systems a permitted activity? Views of councils within the Northland Regional Council jurisdiction.

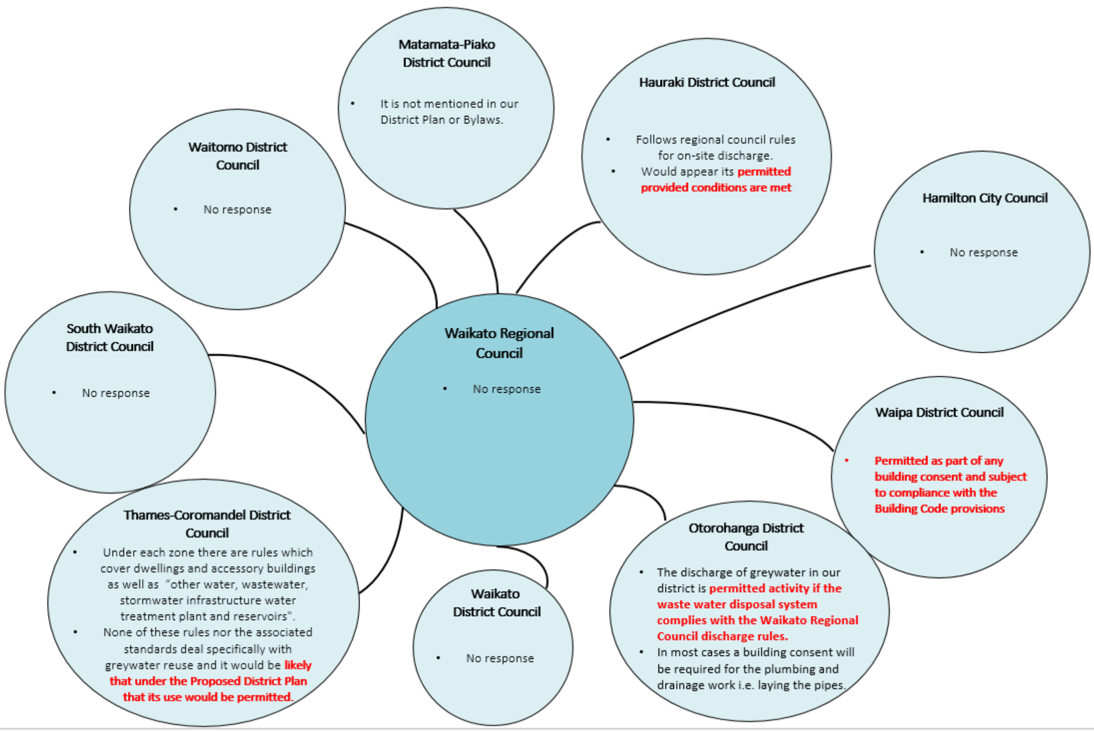

Figure 23. Are greywater reuse systems a permitted activity? Views of councils within the Waikato Regional Council jurisdiction.

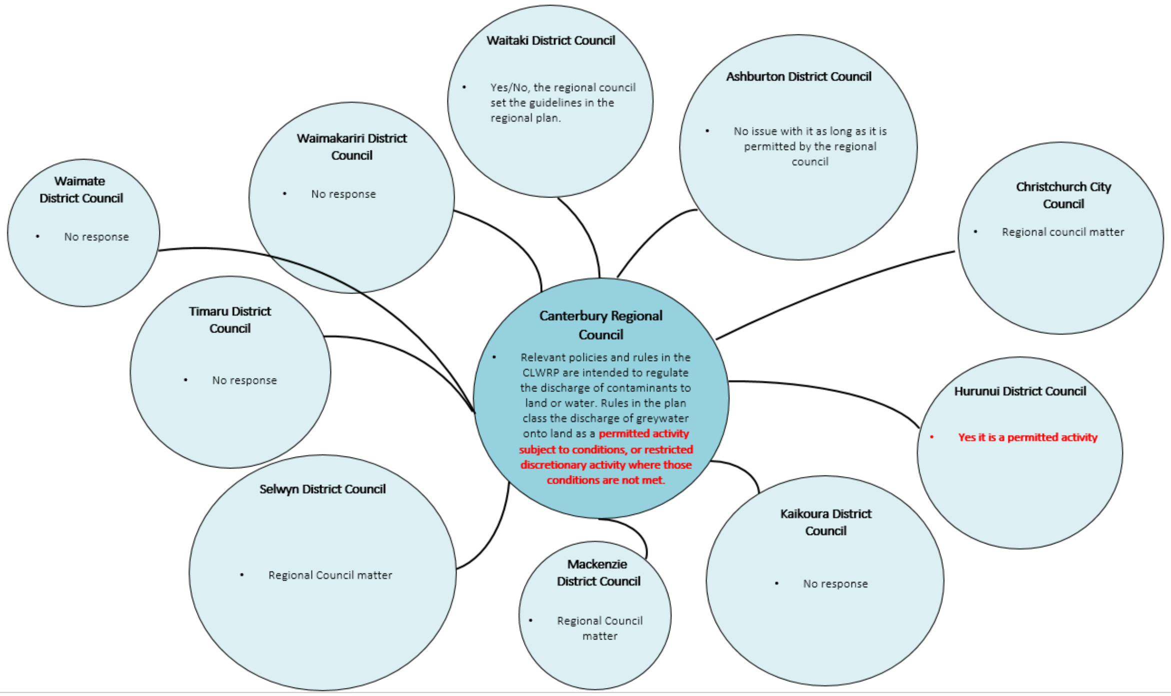

Figure 24. Are greywater reuse systems a permitted activity? Views of councils within the Canterbury Regional Council jurisdiction.

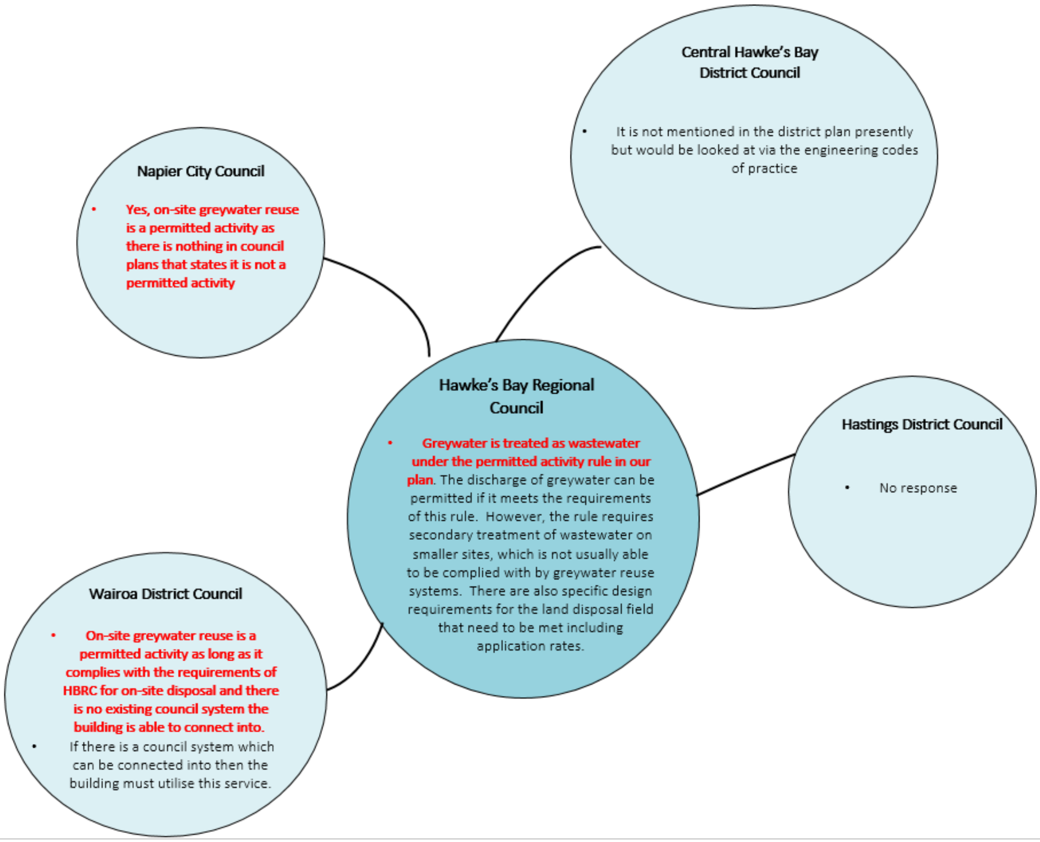

Figure 25. Are greywater reuse systems a permitted activity? Views of councils within the Hawke's Bay Regional Council jurisdiction.

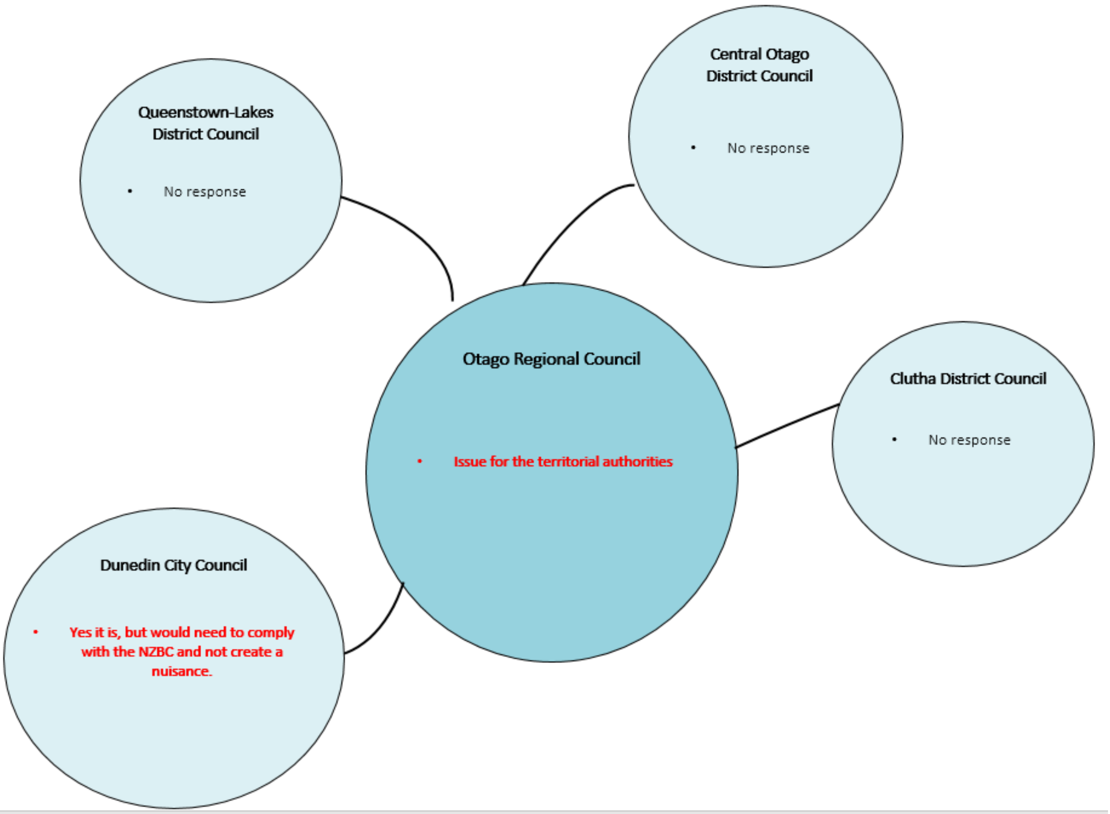

Figure 26. Are greywater reuse systems a permitted activity? Views of councils within the Otago Regional Council jurisdiction.

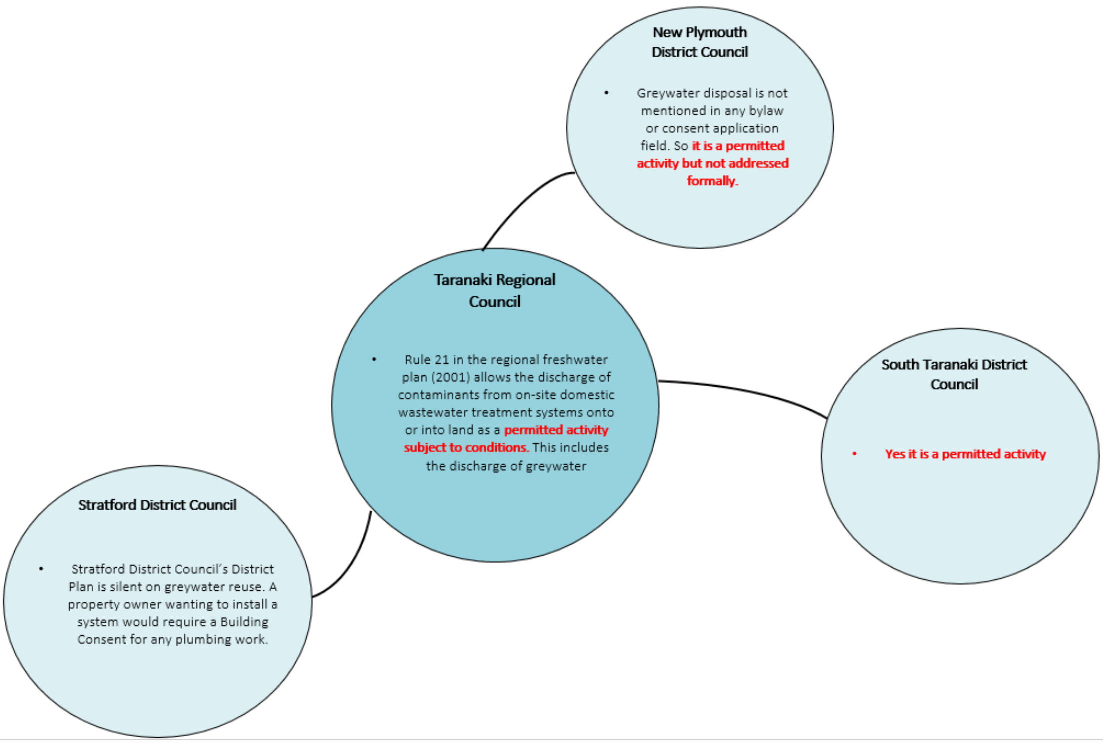

Figure 27. Are greywater reuse systems a permitted activity? Views of councils within the Taranaki Regional Council jurisdiction.

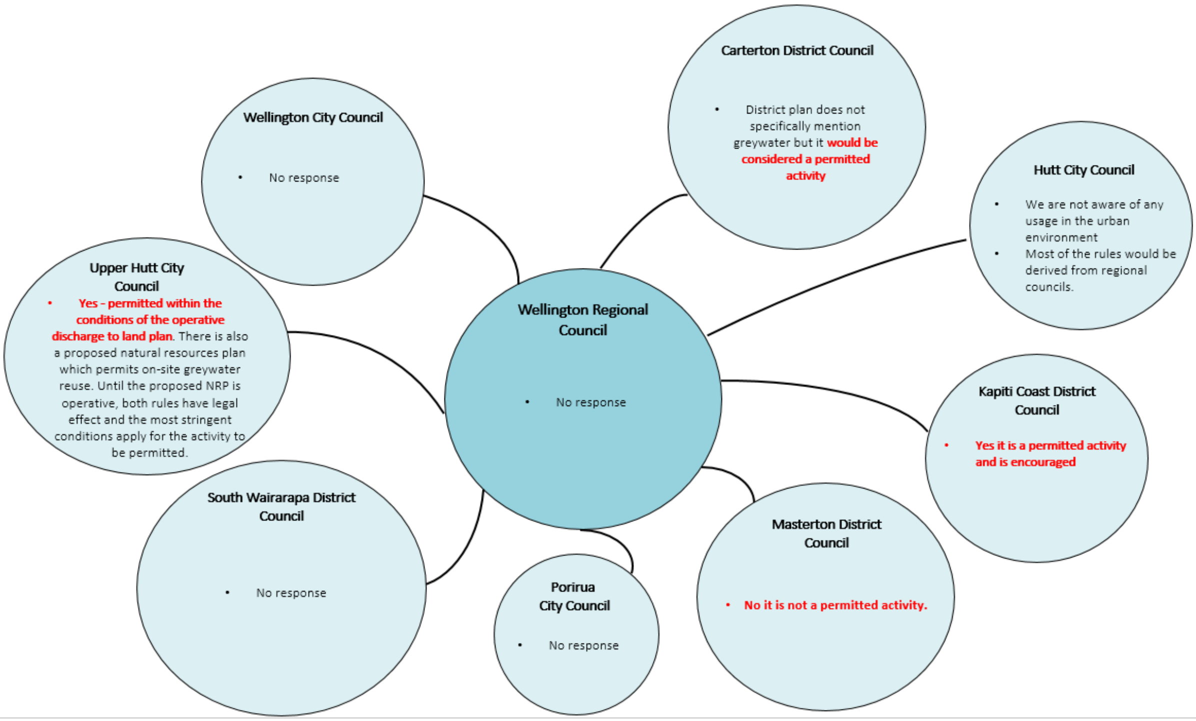

Figure 28. Are greywater reuse systems a permitted activity? Views of councils within the Wellington Regional Council jurisdiction.

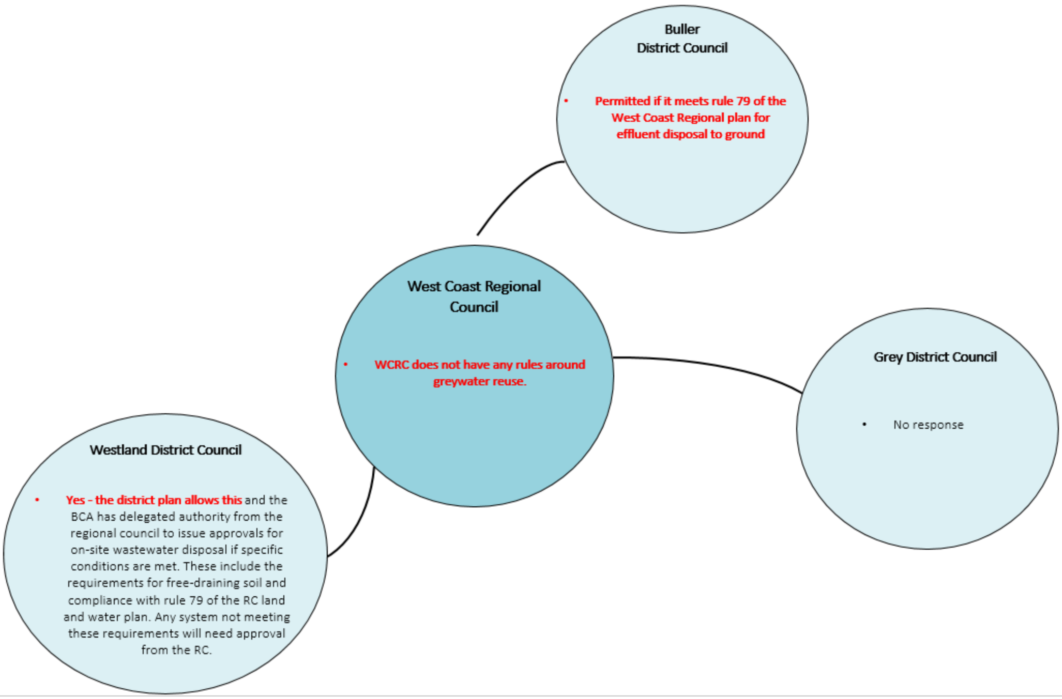

Figure 29. Are greywater reuse systems a permitted activity? Views of councils within the West Coast Regional Council jurisdiction.

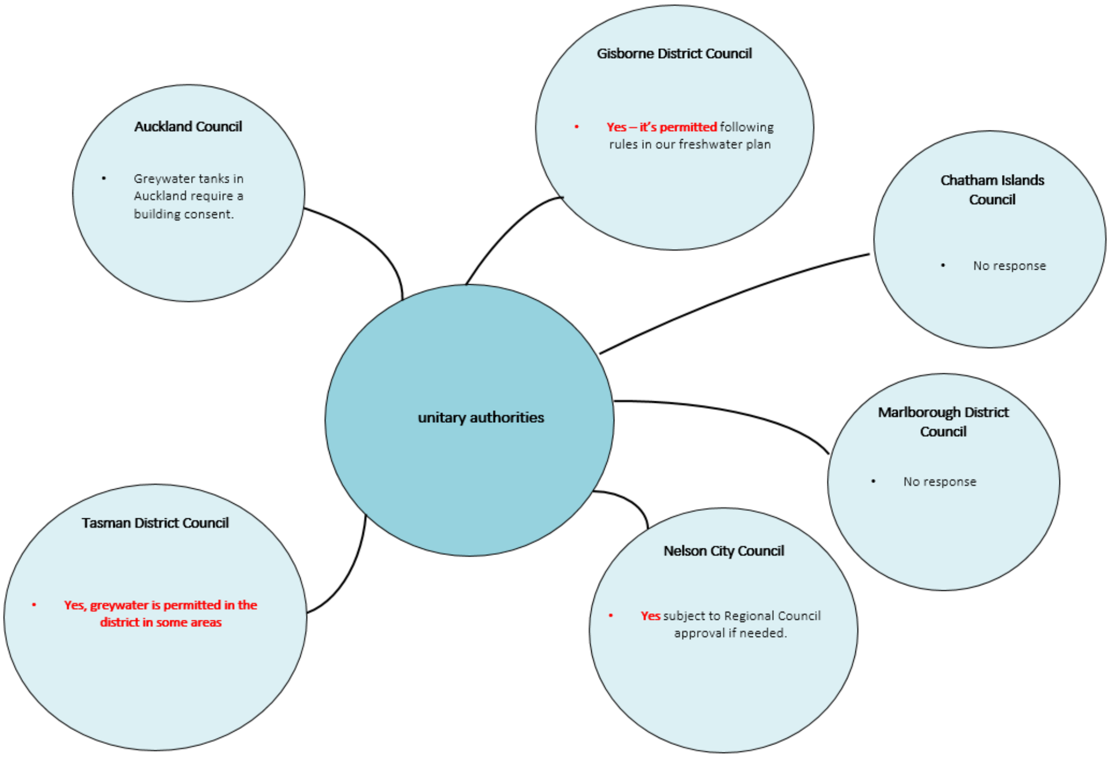

Figure 30. Are greywater reuse systems a permitted activity? Views of unitary authorities in New Zealand.