RAINWATER AND GREYWATER: PERCEPTIONS, PERFORMANCE AND IMPACTS

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ABSTRACT

Over the last 3 years, eight rainwater harvesting and greywater recycling systems in commercial buildings across four New Zealand regions were investigated, of which five systems were also monitored to assess the microbiology and inorganic chemistry. These investigations were undertaken to gain an understanding of their operational performance. A multi-disciplinary approach explored the drivers and barriers to uptake, the operational and financial feasibility of systems in operation and the impacts on the reticulated network.

From over 300 survey responses, cost was listed as the primary barrier to installation as well as the biggest incentive. However, education appears to be the main overarching barrier to uptake. Furthermore, one of the largest perceived drivers to uptake was the positive impact on the water network in terms of delayed infrastructure, environmental benefits and resilience. A key finding in this work is the perceived health risk associated with rainwater and greywater systems.

The eight case study buildings have provided an excellent baseline for both good and poor system design, leading to several learnings that can be adopted in future engineering design guidance. Buildings in Auckland, where volumetric wastewater charges exist, had the greatest financial incentive for reducing water use.

A range of uptake scenarios have been modelled against the four regions to understand the level of impact rainwater harvesting and greywater recycling systems in commercial buildings can have on the water networks.

This research aims to provide the necessary information to increase industry knowledge on rainwater and greywater recycling systems. This includes the drivers and barriers, the operational and financial feasibility of systems in operation and the impacts on the reticulated water network.

KEYWORDS

Rainwater harvesting, greywater recycling, commercial buildings, water network

PRESENTER PROFILE

Since gaining her PhD in Building Science, Lee Bint has been furthering water efficiency research for the last 5 years at BRANZ. She has been involved in the Wellington Young Professionals group and the Water Efficiency and Conservation Network (We Can) special interest group at Water New Zealand.

Amber Garnett recently completed a Master of Environmental Management, where she calculated water footprints and associated water scarcity characterisation factors at different spatial scales across New Zealand. She has a strong interest in water efficiency and conservation research.

1 INTRODUCTION

Almost 100% of New Zealand's commercial buildings rely on a reticulated water network. This means treated potable water is used for hygiene, conditioning and other purposes, including irrigation and toilet flushing. However, there is a need for greater water resilience in our cities.

Population growth and climate change will have an increasing impact on our cities and the buildings we design for them. Forecast climate scenarios for New Zealand suggest that rainfall will vary locally, with the largest variations being seasonal as opposed to annual. It is also predicted that heavy rainfall events will mean stormwater system capacities may be exceeded more frequently, which could lead to surface flooding (Ministry for the Environment, 2016). Smart buildings of the future will be those that are most efficient and sustainable. Water, and the way we use water in our buildings and cities, will increasingly be part of that equation. This is where independent water systems, such as rainwater harvesting and greywater recycling, could prove an effective solution. The application of these systems also has implications on the wider network. Reducing the volume of water that is supplied by the reticulated network reduces the cost of treatment and the infrastructure required to transport this water from source.

At present, there are no New Zealand-specific guidelines to assist and ensure effective delivery solutions for alternative water supplies. Adoption of rainwater and greywater technologies could help to alleviate the burden on urban reticulated water networks. With increasing population and rates of urbanisation compounded by climate change and New Zealand's unique geological landscape, these technologies could form part of the solution to the multi-faceted issue of future water supply and demand in New Zealand.

2 METHODS

To create a holistic overview of the rainwater and greywater system feasibilities, a multi-disciplinary team explored three research areas:

DRIVERS AND BARRIERS TO UPTAKE: This study was undertaken to understand the perceived and actual drivers and barriers to uptake of rainwater harvesting and greywater recycling systems in the New Zealand context. The following methods were used to collect relevant information:

- Two electronic surveys examined participant perception of a wide range of individuals across New Zealand in 2014 (71 respondents) and then again in 2016 (265 respondents).
- A review of published literature and legislation.
- Informal discussions with building-related and water-related industry professionals, including formal workshops.

SYSTEM PERFORMANCE: There are an estimated 41,154 commercial and industrial buildings in New Zealand (Amitrano et al., 2014). Approximately 370 of these building have a rainwater harvesting system, and at least one has a greywater recycling system in operation. Eight of these commercial buildings were assessed for their performance and feasibility. This involved the following:

- Visiting the site and meeting the building manager.
- Reviewing building documentation, plans, costs and maintenance regimes.
- Undertaking a water audit to create a full water balance of the building.
- Monitoring the water use, rainwater and greywater collection and water quality.
- Analysing the overall performance, feasibility and design lessons for each building.

SAVINGS TO WATER NETWORKS: The volumetric impacts on the water networks were calculated for the four regions the case study buildings are located in. This involved two series of analysis – the current and the future impacts to the water networks over 50 years. These are based on a range of potential uptake scenarios. To do this, the following data inputs were examined:

- Metered mains water.
- Harvesting rainwater.
- Recycled greywater.
- Current and forecast regional water demand.
- Current and estimated non-residential building stock, based on building consents.

Throughout the research period, an industry advisory panel was established as a forum for advice on the direction of the research and to provide reality checks on the various aspects of the work.

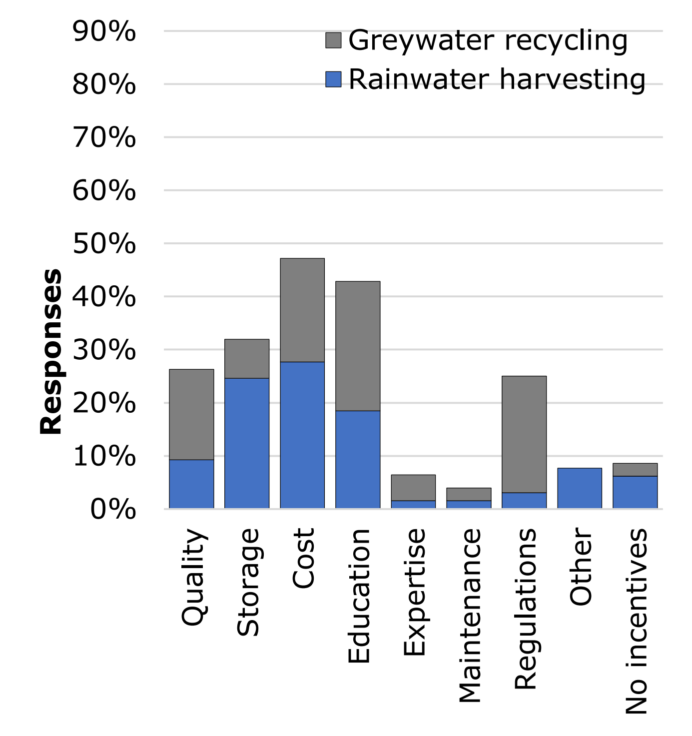
3 DRIVERS AND BARRIERS TO UPTAKE

Internationally, there have been numerous studies examining the barriers and drivers for rainwater harvesting. A leading study by Ward (2010) summarised how the international perspective divides the barriers into four themes – institutional, economic, technological and educational. Many of the specific subthemes from this international study reflected the New Zealand findings (shown in red in Table 1). The overarching issue was the knowledge gap of rainwater harvesting systems, especially for non-residential systems.

Table 1: Barriers to rainwater harvesting implementation – an international perspective (Ward, 2010).

Institutional	**Economic**	**Technological**	**Educational**
Insensitive government attitudes	Cheap mains water	Shortage of suitably qualified specialists	Emotional resistance
Water lobbies with special interests	Perceived abundance of water	Reduced summer efficiency due to climate change	Health and safety fears
Political structures with diverging interests	Long pay-back periods	Difficulties with operation/ maintenance	Lack of straightforward guidance
Lack of interest from water providers	Initial capital outlay, especially as retrofit	Seen as an unproven technology	Unfamiliarity with technology
Lack of willingness towards innovation	Unproven cost benefit	Lack of clearly defined water quality and other standards	Seen as an unconventional approach

From the two surveys, cost, education and storage were the largest perceived barriers for rainwater, while education and cost were the two biggest barriers to greywater recycling.



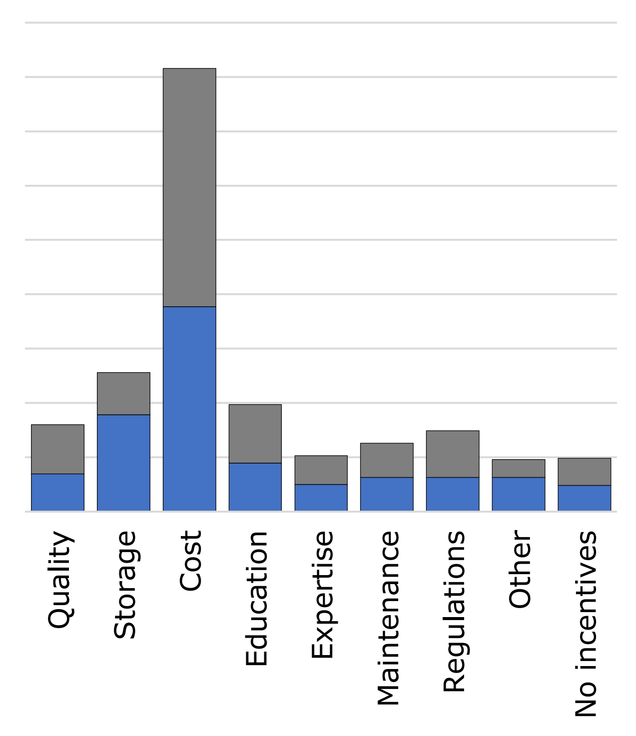
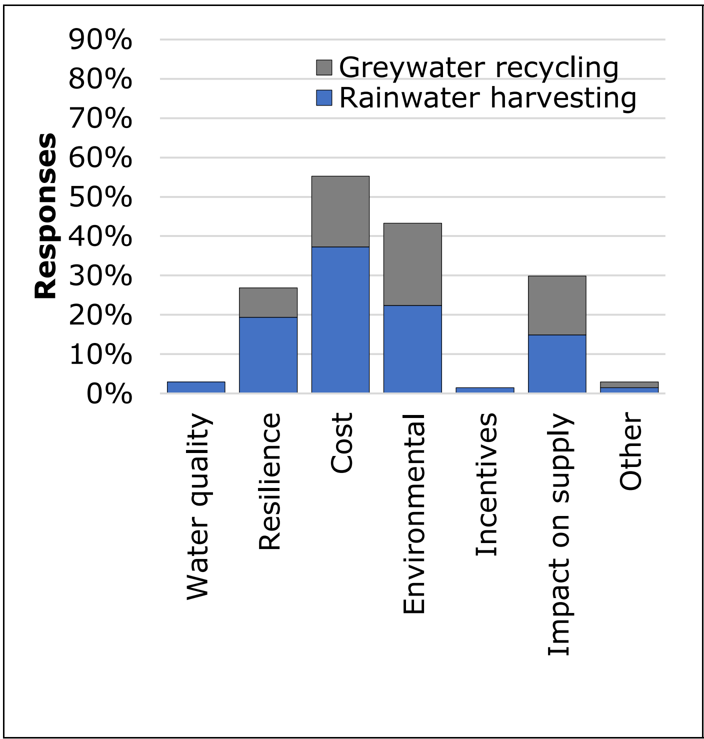


Figure 1: 2014 barriers to uptake.

Figure 2: 2016 barriers to uptake.

As an example, industry feedback suggests a maximum pay-back period of 3–5 years is expected before management will approve inclusion in building design, which is a very strict timeframe.

The biggest incentives or drivers for installing rainwater and/or greywater systems were cost savings and environmental responsibility. In addition, a secondary (but equally important) reason for installing rainwater and/or greywater was for resilience, i.e. to ensuring a building's function is maintained during and after a natural disaster.



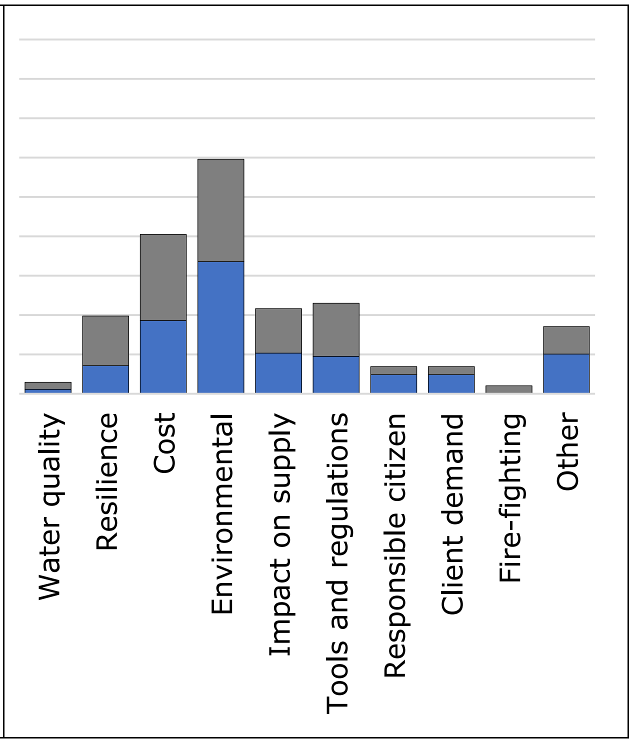


Figure 3: 2014 drivers for uptake. *Figure 4: 2016 drivers for uptake.*

However, respondents' primary concerns with rainwater or greywater systems showed that water quality, health concerns and waterborne disease are by far the biggest perceived issues. For greywater quality specifically, the recurrent respondent concerns were:

- health concerns
- general quality
- cross-contamination with potable water
- cleanliness of the system
- society's perception of 'dirtiness'.

While cost savings and environmental reasons were the main drivers for installation, this shows that the underlying lack of knowledge and uncertainty with regard to health implications were perceived to outweigh the potential benefits. There was found to be an underlying resistance to the system's implementation as a result.

4 SYSTEM PERFORMANCE

There are estimated to be at least 371 commercial buildings across New Zealand with a rainwater harvesting and/or greywater recycling system in operation. Eight of these were investigated in detail between 2014 and 2017, as summarised in Table 2. Despite ranging in building use, size and location, these buildings all used the rainwater and greywater for the flushing of toilets and urinals.

Table 2: Case study building summary.

Building	Type	Region	Net lettable area	System
A1	Office	Auckland	28,663 m^2	Rain
A2	Office/warehouse	Auckland	2,440 m^2	Rain
A5	Office	Auckland	9,366 m^2	Rain
B1	Retail	Bay of Plenty	32,323 m^2	Grey + rain
C1	Education/office	Canterbury	2,143 m^2	Rain
C2	Education/service	Canterbury	7,395 m^2	Rain
C3	Office	Canterbury	23,000 m^2	Rain
W1	Education/service	Wellington	9,727 m^2	Rain

4.1 VOLUMETRIC PERFORMANCE

All case study buildings proved to be better than the average in terms of water efficiency, as measured by the total building water use intensities. The total building water use intensity in the buildings ranged between 0.13 and 1.13 kL/m^2/year. This is consistently lower than the average range of New Zealand benchmarks (0.76–1.03 kL/m^2/year), indicating that the water efficiency was already incorporated into the building design.

Table 3: Water, rainwater and greywater use in case study buildings.

Type	Water use (kL/year)							
	A1	**A2**	**A5**	**B1**	**C1**	**C2***	**C3**	**W1**
Mains	9,275	194	3,249	22,659	237	6,605	11,727	6,833
Rainwater	2,661	113	682	695	394	1,780	5,372	641
Greywater	-	-	-	171	-	-	-	-
TOTAL	**11,935**	**307**	**3,931**	**23,526**	**631**	**8,385**	**17,099**	**7,474**

**Mains water data was not recorded and is not monitored – this is a predicted number only.*

In addition to the water use information in Table 3, the monitoring of eight commercial buildings found a range of rainwater use:

- 45–1,147kL during summer.
- 22–1,039kL during winter.

The average proportion of total water use that comprised of non-potable, non-contact use (i.e. toilets and urinals) was 23%. This indicates a potential saving of 23% of total water from the water network. This also equates to a financial saving for both the building owner and the water service provider.

The feasibility of each rainwater harvesting and/or greywater recycling system to supply the required non-potable, non-contact demand throughout the year is assessed in Figure 5. This is presented as a percentage of the annual non-potable, non-contact demand that is either met in full, in part or not at all (none).

However, it should be noted that only two of the case study buildings (C1 and W1) were using the water systems to their full advantage. The others have significant underutilised potential.

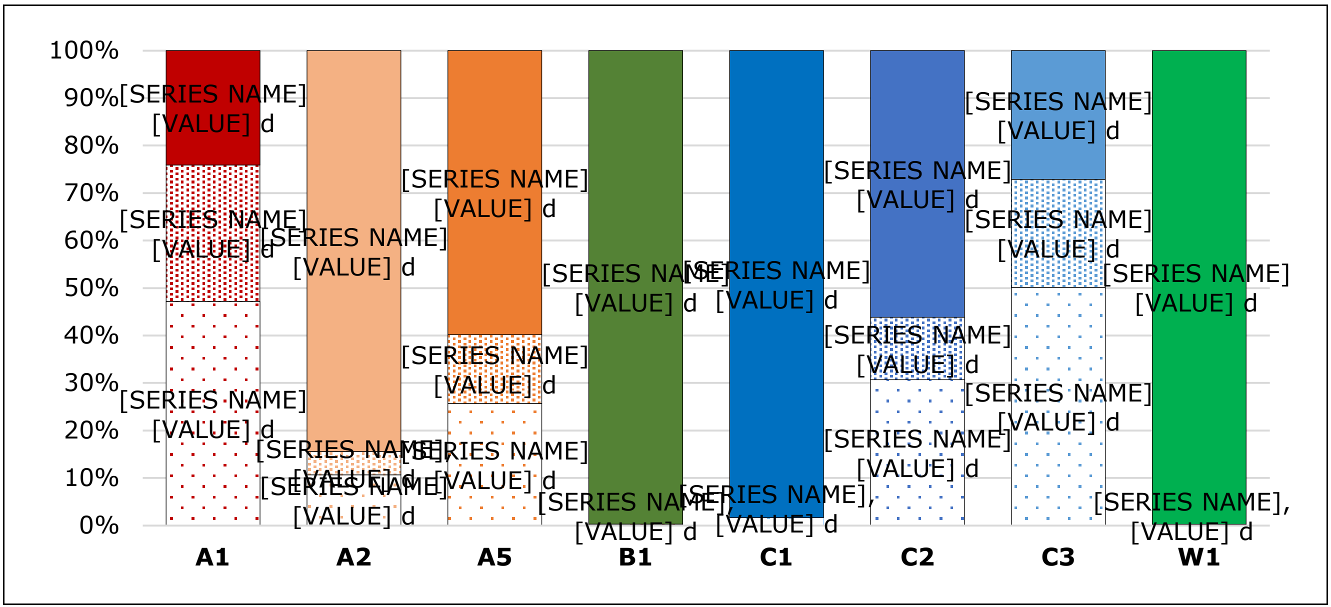


Figure 5: Specified flushing demand met by rainwater/greywater as days per year (d).

Much of the water sourced from the rainwater systems occurred between March and November each year, with lower supply during the drier, summer months (refer Figure 6). Rainwater supplied between 9% and 62% of total water demand or an average of 89% of the case study buildings' non-potable, non-contact demand.

A more consistent year-round average was found from the greywater system. However, the system was not being utilised to its full potential, by only supplying one toilet block. This equates to just 4% of the total water demand or 10% of the building's non-potable, non-contact demand.

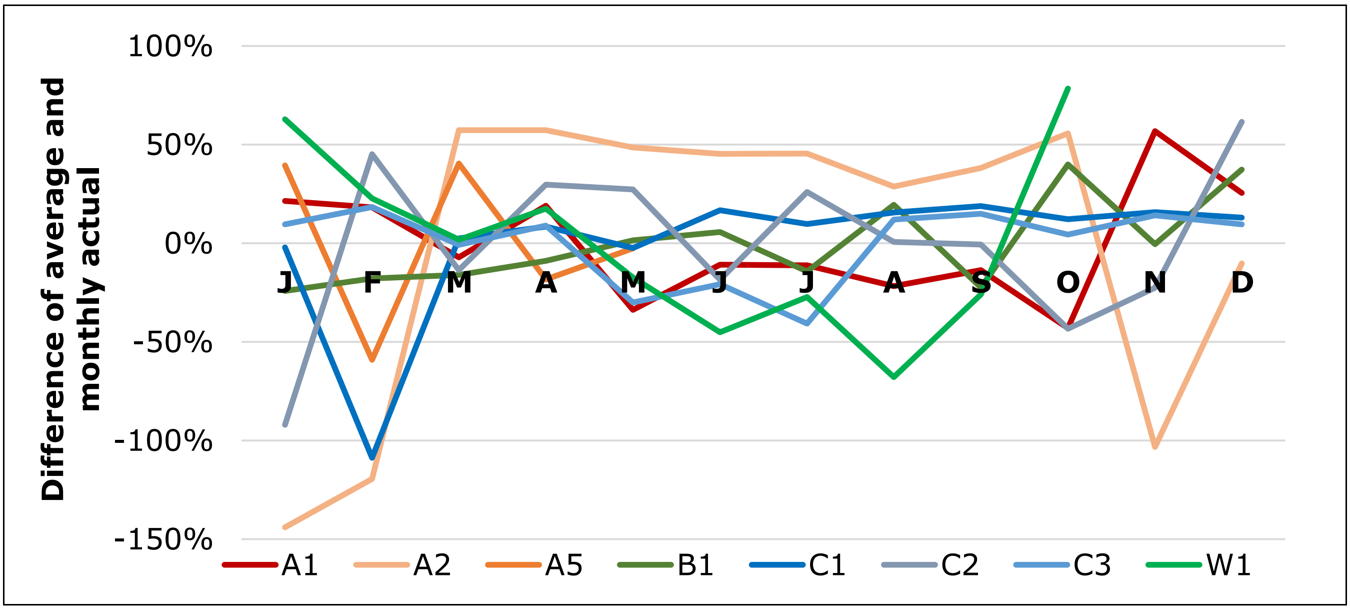


Figure 6: Monitored rainwater and/or greywater use – divergence from average.

4.2 FINANCIAL PERFORMANCE

The financial feasibility is almost entirely dependent on the presence of volumetric wastewater tariffs. In Auckland, both potable water and wastewater are charged volumetrically. Outside of Auckland, a range of charging mechanisms exist. These include volumetric or bulk allocation charging for potable water through to wastewater charged as a percentage of land or a building's capital value as part of the council rates.

Despite having poor financial pay-back periods in their own regions (3.3–63.8-year pay-back), applying the Auckland-based tariffs to all case study buildings meant the systems became more financial feasible (1.6–20.9-year pay-back). The charging mechanisms (i.e. volumetric wastewater tariffs) outside of the Auckland region are not providing the financial incentives to lower the use of water or become less reliant on the mains reticulated networks. This is especially important where user resilience is a key driver and cost is a key barrier. Therefore, in addition to the drivers identified in this research, the observed uptake rate is also influenced by water service provider charging mechanisms.

Table 4 shows that the utilisation of rainwater harvesting and/or greywater recycling systems in Auckland is typically feasible. Outside of Auckland, fixed wastewater charges are hidden in council rates and provide no incentive for water efficiency or conservation. On top of this, lack of education, guidance and standards are creating barriers at all levels.

Table 4: Cost-benefit information.

Building	**Pay-back period** (years)		**Benefit-cost** (25 year)		**IRR** (25 year)	
	Actual tariff	Auckland tariff	Actual tariff	Auckland tariff	Actual tariff	Auckland tariff
A1	3.32	3.32	3.04	3.04	25.32%	25.32%
A2[1,2]	20.66	20.66	0.25	0.25	N/A	N/A
A5[1]	7.68	7.68	0.58	0.58	N/A	N/A
B1	63.75	20.89	0.19	0.57	-7.57%	-0.01%
C1[1,3]	-	9.99	-	1.03	-	2.06%
C2[3]	-	N/A	-	N/A	-	N/A
C3[1,3]	-	1.61	-	7.85	-	39.55%
W1[1]	20.27	8.43	0.62	1.50	1.38%	10.02%

[1] Costed at 2017 price due to unavailability of costing information at the time of build.
[2] The actual costs associated with the rainwater system redesign are included in the capital cost.
[3] The Canterbury buildings are not charged a volumetric rate until their allocation is used.

4.3 WATER QUALITY AND HEALTH RISK

Four of the case study buildings also had their rainwater quality tested monthly over 1 year. All samples were taken prior to any treatment (if any). The results were then compared to published literature to inform the most appropriate indication of acceptable microbial and inorganic chemical contaminant levels. The Drinking Water Standards for New Zealand were used for this comparison (Ministry of Health, 2008).

Rainwater inorganic chemical results were mostly less than the current drinking water maximum acceptable values or guideline values for New Zealand. All samples were also well below the modified values, which were recalculated to reflect the lower volume of toilet flush water expected to be used compared to drinking water. Rainwater was also analysed for microbiological contaminants, specifically the indicator organism *Escherichia coli* and two pathogenic species (*Salmonella* spp. and *Campylobacter* spp.). Of the 18 samples with *E. coli* detected, 11 were from the same building. This building did not have an enclosed tank, which is the only distinction between the other buildings sampled. These inorganic chemical and microbial results are reasonably consistent with previous New Zealand studies (Siggins & Cressey, 2017) and show that, with correct design and maintenance, a high water quality can be maintained before any treatment or filtration.

Greywater was sampled both before and after filtration and treatment. Monthly samples were taken both pre-treatment and post-treatment and tested for the same inorganic chemical and microbial parameters as the rainwater samples. Of the inorganic chemicals determined in the greywater samples, only aluminium exceeded the guideline value in a single sample. However, it should be noted that the guideline values in New Zealand drinking water standards are for aesthetic water qualities only. For the microbial analysis, *E. coli* was found in three pre-treatment samples in low levels. No *E. coli* or other microbial detections occurred post-treatment. In addition, quarterly samples of greywater were taken from before treatment only and were tested for *Giardia* spp., *Cryptosporidium* spp. and culturable adenovirus. No pathogens were detected in these samples. Overall, the quality of greywater in this single case study building is better than expected. More work is required to make this statement more representative.

5 SAVINGS TO WATER NETWORKS

The current impacts of the case study buildings were projected forward 50 years to 2066 across the four New Zealand regions where the case study buildings were located. To gain an indication of the potential volumetric savings to the water network, a range of building uptake and water demand scenarios were assessed.

Uptake scenarios were based on current and projected building consent figures against a recent non-residential building stock database. This applies to both new build and retrofit uptakes ranging low, medium and high. Furthermore, rainwater and greywater is used to supply non-potable, non-contact water demand (refer Figure 5), which is found to be 23% of total water demand across all case study buildings. This is used as an optimistic supply scenario (in Table 5) where non-potable demand acts as the volume achieved. The observed scenario applies the actual savings demonstrated in the case study buildings.

Table 5: Scenario definition.

<table>
<tr><th>Building uptake</th><th>Low</th><th colspan="2">Medium</th><th>High</th></tr>
<tr><td>New build</td><td>10%</td><td colspan="2">20%</td><td>30%</td></tr>
<tr><td>Retrofit</td><td>0%</td><td colspan="2">10%</td><td>20%</td></tr>
<tr><th>Rain/grey supply</th><th colspan="2">Optimistic (23% average)</th><th colspan="2">Observed (19% average)</th></tr>
<tr><td>Auckland</td><td colspan="2">14%</td><td colspan="2">25%</td></tr>
<tr><td>Bay of Plenty</td><td colspan="2">28%</td><td colspan="2">4%</td></tr>
<tr><td>Canterbury</td><td colspan="2">42%</td><td colspan="2">38%</td></tr>
<tr><td>Wellington</td><td colspan="2">9%</td><td colspan="2">9%</td></tr>
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Based on the limited number of case study buildings, Table 6 shows the potential volume of mains water that could be alleviated from the water network, assuming an average total water use (as per the case study buildings) and an optimistic supply of 23% non-potable usage.

Table 6: Annualised savings to the water network from scenarios.

	Predicted annual water savings (kL/year)		
	Low uptake	**Medium uptake**	**High uptake**
Optimistic:			
Auckland	665,698 kL	1,353,515 kL	3,372,728 kL
Bay of Plenty	199,743 kL	428,112 kL	1,055,967 kL
Canterbury	925,170 kL	2,676,118 kL	6,277,406 kL
Wellington	514,361 kL	1,170,473 kL	2,855,307 kL
Observed:			
Auckland	585,814 kL	1,191,093 kL	2,968,000 kL
Bay of Plenty	109,859 kL	235,462 kL	580,782 kL
Canterbury	535,625 kL	1,549,332 kL	3,634,288 kL
Wellington	125,733 kL	286,116 kL	697,964 kL

When the buildings were aggregated by region, the volume of non-potable demand that is able to be supplied varies (refer Table 5). Accordingly, a second supply scenario was used to project future savings to the water network based on observed usage at a regional level.

When compared to the regional water demand forecasts in 2066 (Figure 7), the volumes of potential water that can be saved are comparatively low. By increasing the water end-uses for non-potable water, an increase in the potential water savings to the networks could be seen. The results of this research show that, whilst there is a reduction in network demand, it does not significantly reduce the amount of supply required to meet future demands.

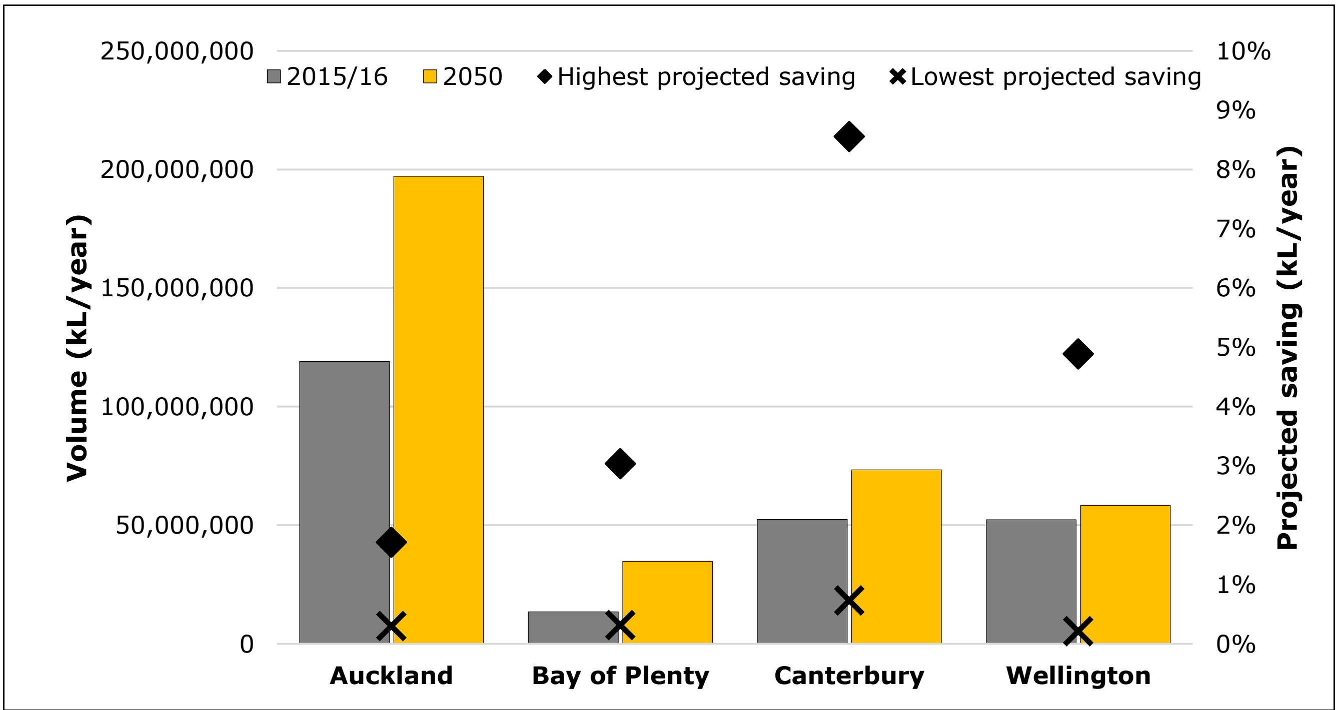

Figure 7: Current and projected regional water demand.

Projecting the result from the 2015/16 case study data with specific uptake scenarios shows the potential volumetric savings possible for the water network in the future based on estimated new builds and uptake scenarios alongside two supply scenarios. The addition of more commercial buildings data to this analysis would help to build a more comprehensive picture of potential future impacts of using rainwater harvesting and greywater recycling technologies across New Zealand.

Perhaps a large and somewhat overlooked advantage of using rainwater harvesting and/or greywater recycling systems is the capacity to maintain supply given conditions in which the reticulated network is constrained. Resilience against natural disaster, for example, flood events can result in reduced water availability due to water treatment facilities becoming overwhelmed by increased flows and sediment content. Whilst rainwater and/or greywater would be used for non-potable uses only, reducing the peak demand for treated water during these events would be beneficial as well as for overflow storage.

6 DISCUSSION AND CONCLUSIONS

The two self-selecting surveys found the following key areas of research, which have been explored through further building and water network assessments:

- Cost – one of the incentives and also one of the barriers.
- Storage – one of the barriers.
- Water quality – the primary concern with the use of rainwater and greywater.
- Water quantity – resilience was one of the incentives, as was cost.
- Education – one of the barriers.

6.1 COST

Whilst cost savings were one of the largest drivers for the installation of rainwater harvesting and greywater recycling systems, the cost of installation was also found to be one of the greatest barriers to uptake. The financial incentive to install rainwater and greywater systems is almost entirely dependent on volumetric water and wastewater tariffs. The eight case study buildings showed that, despite having poor financial pay-back periods in their own regions, using Auckland's wastewater tariff meant the systems became financially feasible. The Auckland region is the only water service provider to volumetrically charge for wastewater. It was determined that, by including wastewater charges in general rates, the incentive to conserve water was reduced. Thus, the tariff structures themselves act as a barrier to uptake and to water efficiency and conservation more generally.

Furthermore, throughout the site visits and subsequent monitoring of the eight case study buildings, it was found that only two were using their rainwater and/or greywater system in the most effective way. This meant cost savings were not being maximised. Thus, whilst the findings of this research can give an indication of the potential financial savings of installation in a range of commercial buildings, it should be noted that there is room to improve the design and operational performance of the systems.

6.2 WATER QUALITY

In terms of greywater quality, the specific recurring issues were health, water quality, cross-contamination with potable water, cleanliness of the system and society's perception of 'dirtiness'. In response to these concerns, the water quality of rainwater harvesting and greywater recycling systems was tested. The water quality study concluded that there is likely to be little or no potential human health risk surrounding the use of rainwater and greywater for toilet and urinal flushing. However, noting that only five buildings formed this part of the study, results cannot be considered representative. In addition to the drivers and barriers identified, some regulations are prohibitive and therefore create a barrier to installation and/or effective utilisation. For example, rainwater cannot be used in cooling towers. This further shines the spotlight on the level of overarching education needed.

6.3 WATER QUANTITY

Six of the case study buildings were deems to be underutilising their rainwater harvesting and/or greywater recycling potential, therefore negating the benefits of installing these systems. An analysis of eight case study buildings found that, on average, 23% of a building's total water use was for non-potable, non-contact purposes. Therefore, under an optimistic supply scenario, rainwater and/or greywater sources could account for up to a 23% reduction in potable water from the reticulated network. However, it was found that, in reality, not all regions were achieving these savings. Therefore, under an observed scenario, the supply rates were found to vary from 4% through to 38% of total water use. The greatest potential savings can be seen for the Canterbury region under all building uptake scenarios.

As the case study buildings were limited in frequency and regional range, their volumetric impact on the potable water network is considered minor. However, with increased uptake and in combination with residential rainwater harvesting and/or greywater recycling systems, the capacity for these systems to reduce the network demand would increase.

The value of alternative water sources will only increase in future years as our population and rates of urbanisation increase. Expected increases in population creates an expected supply deficit of, for example, 148 ML/day in Auckland alone (Klein et al., 2015). At present, most regions of New Zealand have at least one river and/or aquifer that is either fully allocated or overallocated or is likely to be so in the next 5 years (New Zealand Business Council for Sustainable Development, 2008). The need for further research into alternative water sources will become more prevalent in future years.

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