Study Report

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Performance of commercial rainwater and greywater systems

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Last, but certainly not least, are the owners and managers of the eight case study buildings detailed throughout this report. Their interest and willingness to participate, receiving us on site and answering (very) many questions over the last 3 years has been a rewarding and enlightening experience. The information from these buildings is the basis of this research, of which could not be conducted without their support.

Note

This report is intended for dissemination as a publicly available BRANZ study report. It is based on the research undertaken between 1 April 2014 and 31 March 2017.

Performance of commercial rainwater and greywater systems

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Author

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Abstract

This study was undertaken to understand the actual performance and the practical and financial feasibility of commercial rainwater harvesting and greywater recycling systems in operation in New Zealand. Eight case study buildings were examined between 2014 and 2017. This included water audits, monitoring of water, rainwater and greywater quantity and quality and ongoing discussions on the management of the systems with building managers.

It was found that the buildings with the systems in operation were generally more water efficient to begin with, demonstrated by their water use intensity. Each building had its own set of design lessons, which provide a great opportunity for the design of any future buildings incorporating rainwater and/or greywater systems. Some of these included the way monitoring and mains switchover mechanisms are designed, energy efficient storage and distribution design and education and maintenance requirements for new building owners and managers.

In response to the findings in Bint & Jaques (2017), rainwater and greywater quality was tested over a 12-month period. The results of a health risk assessment concluded that there was a very low risk of infection from the flushing toilets and urinals. However, a representative level of risk that these systems pose cannot be established.

Overall, the utilisation of rainwater harvesting and/or greywater recycling systems in Auckland is typically feasible. Outside Auckland, fixed wastewater charges are hidden in council rates and as a result provide no incentive for water efficiency or conservation. On top of this lack of financial incentive, the lack of education, guidance and standards for the design and operation of the systems are creating institutional and educational barriers.

Keywords

Rainwater harvesting, greywater recycling, feasibility, system operation, commercial building, water end use, quality, health risks, cost benefit

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Executive summary

There are an estimated 41,154 commercial and industrial buildings in New Zealand (Amitrano et al., 2014). Approximately 370 of these buildings have a rainwater harvesting system, and at least one has a greywater recycling system in operation. Eight of these buildings were assessed by BRANZ between 2014 and 2017 for their performance and feasibility.

These case study buildings all proved to be better than the average in terms of water efficiency, as measured by the total building water use intensities. All measured below the median water use. However, it is felt that only two of the case study buildings were using the water systems to their full advantage. The others have significant underutilised potential for improving the efficiency of the installed system. It was also identified that, in addition to the findings from Bint & Jaques (2017), some regulations are prohibitive and therefore create a barrier to installation and/or effective utilisation.

Several design failures and lessons were observed through site investigations, as-built documentation, discussions with building managers and users and analysis of monitored water data. The three biggest design lessons are:

- user-friendly monitoring and straightforward switchovers from rainwater and/or greywater to mains water
- better storage and distribution design has the potential to significantly reduce additional pipe, pumping and ongoing energy costs
- improved education for building managers and clearly laid out long-term maintenance plans and/or schedules.

The economic feasibility is almost entirely dependent on volumetric wastewater tariffs. The systems would have been financially feasible under current Auckland water charges. However, the differences in the way water and wastewater is charged between regions means that non-Auckland-based systems tended to have poor financial payback periods. The simplistic charging mechanisms (i.e. a lack of specific volumetric wastewater tariffs) outside Auckland are currently insufficient to incentivise water efficiency and reduce reliance on the main reticulated networks. Therefore, the uptake of rainwater and greywater systems is not only a building issue but also a water service provider and infrastructure issue.

In response to the primary finding of Bint & Jaques (2017), the water quality study found there is likely to be little or no potential human health risk surrounding the use of rainwater or greywater for toilet and urinal flushing. This further puts the spotlight on the need for a level of overarching education on the operation and risks associated with system operation.

In summary, the utilisation of rainwater harvesting and/or greywater recycling systems in Auckland is typically financially feasible. Outside Auckland, fixed wastewater charges are hidden in council rates and provide no incentive for water efficiency or conservation. On top of this, the lack of education, guidance and standards on the design and operation of the systems create barriers.

The findings of this work, together with Bint & Jaques (2017) and Garnett & Bint (2017), are the first step towards identifying those barriers.

1. Introduction

Most commercial buildings are totally dependent on reticulated water networks. Treated potable water is used for hygiene, conditioning and other purposes, including toilet flushing and landscape irrigation. Their managers are largely unaware of the success and benefits of rainwater harvesting and/or greywater recycling systems such as reduced water and wastewater tariffs. There is also little awareness of the benefits of improved monitoring such as leak detection. An increasing number of building and facilities managers have indicated their desire to understand the feasibility of installing alternative water sources into the commercial buildings in their portfolios.

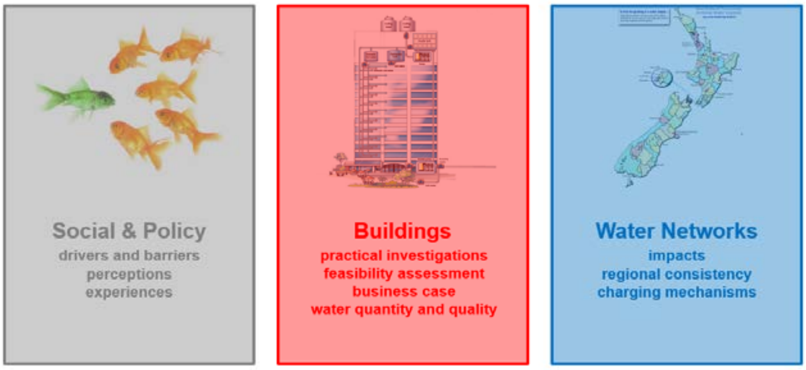
As demonstrated in Christchurch, where 80% of the city's waste and wastewater network was severely damaged in the 2011 earthquakes, there is also a need for greater resilience in commercial buildings. This is where independent water supply systems, such as rainwater harvesting and greywater recycling could play a role in freshwater allocation and reuse.

Feedback from several designers suggest higher water use targets are now frequently being considered. This is currently no New Zealand-specific guidance to assist and ensure delivery solutions will work effectively in this area.

1.1 Research approach and aim

To create a holistic overview of the rainwater and greywater system feasibilities, a multi-disciplinary team, led by BRANZ, has explored three research streams:

- Social and regulatory drivers and barriers to uptake of the systems.
- Investigations of buildings with rainwater harvesting and/or greywater recycling systems in operation.
- Impacts on the three water networks (potable water, stormwater and wastewater).



Work in the preceding study report (Bint & Jaques, 2017) helped to derive the following questions, which form the research summarised within this report on eight case study commercial buildings:

- Education and awareness – available information and the level of understanding.
- Water quality – acceptable versus actual and health impact assessment.
- Resource consumption – building water and energy use and water savings.
- Feasibility – financially and operationally.
- Issues and considerations – industry status and performance and design implications.

1.2 Structure of the report

This report should be read in combination with the other BRANZ study reports in this series (Bint & Jaques, 2017; Garnett & Bint, 2017). The following structure is reported:

1. **Introduction** – sets the scene of the research and defines key research questions.
2. **Building assessments** – provides the methodology, recruitment and assessment method for the eight case study buildings forming the content of this research report.
3. **Capture, storage and demand** – discusses the building performance in terms of quantity of water drawn from the mains water networks and benchmarks based on building use and size.
4. **System design and operation** – steps through the assessment of collection, conveyance, filtration and treatment, storage and distribution components of the case study buildings.
5. **Water quality and health risk** – highlights the findings from the monthly water quality and health risk assessments undertaken by the Institute of Environmental Science and Research (ESR).
6. **Feasibility assessment** – the economic analysis is reported, using capital and operating costs and savings associated with the case study buildings.
7. **Summary** – discusses the overall findings from the case study buildings and sets up key questions for future work.

- **Appendices** – contain tables detailing case study building characteristics and water quality testing results.

2. Building assessments

This section aims to set the scene for New Zealand's commercial buildings and to provide a clear methodology for undertaking the building assessments.

2.1 Recruitment

The Building Energy End-use Study (BEES) stratified the sample by building size and building use. This estimates that there are 41,154 commercial buildings across New Zealand, as shown in Table 1 (Amitrano et al., 2014).

Table 1. Commercial buildings by size strata (Amitrano et al., 2014).

Building size strata	Area (million m^2)	Count (number)	Average (m^2)
S1: 5–649 m^2	8.2	27,609	298
S2: 650–1,499 m^2	7.7	8,007	955
S3: 1,500–3,499 m^2	7.8	3,544	2,198
S4: 3,500–8,999 m^2	7.8	1,496	5,187
S5: >8,999 m^2	8.5	499	17,014
Total	**39.9**	**41,154**	**970**

The exact number of commercial buildings that have rainwater and/or greywater systems in operation is unknown. It has been estimated at 370 buildings, based on information collected from the following sources:

- Existing databases – drinking-water register for New Zealand (Institute of Environmental Science and Research, 2017).
- Published information on their journey and/or performance – Green Star New Zealand certified buildings (New Zealand Green Building Council, 2017a; New Zealand Green Building Council, 2017b)
- Word of mouth and website enquiries.

Figure 1 shows commercial buildings with rainwater and/or greywater systems overlaid with mean annual rainfall by region. This shows that only a small proportion of these buildings are in water-stressed areas. In fact, most of the identified buildings are rural educational buildings that may not have access to mains reticulated supply and therefore solely rely on rainwater to meet their water demand.

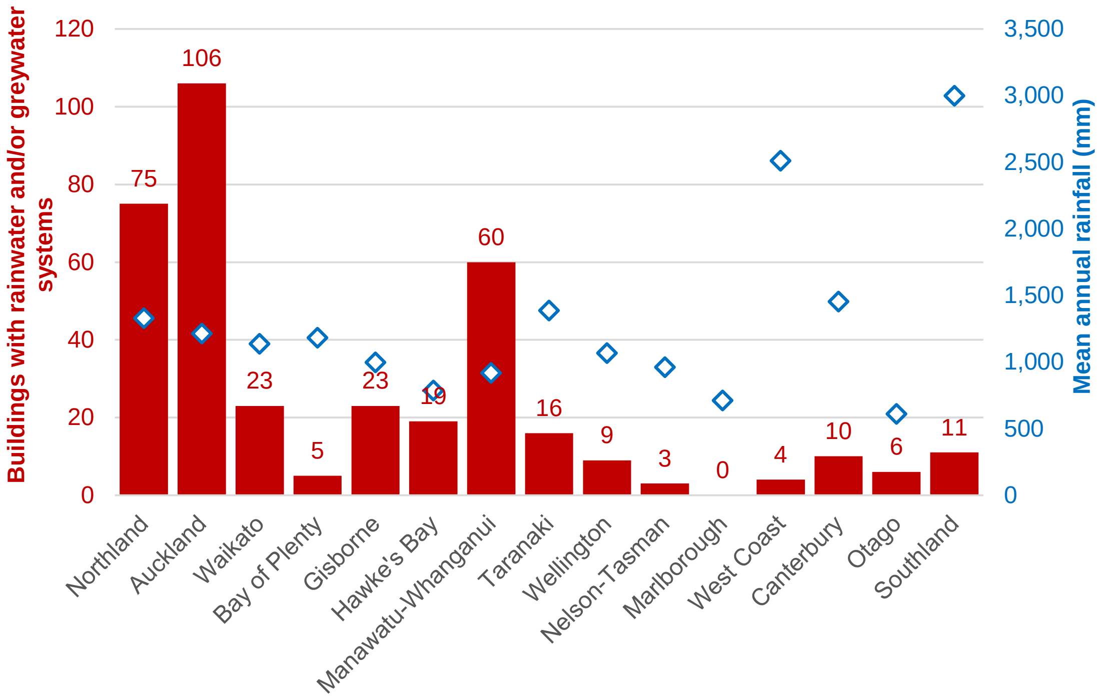


Figure 1. Commercial buildings with rainwater and/or greywater systems in New Zealand by region.

Upon closer inspection, only one of the identified buildings had a greywater recycling system. This is due to the misuse of terminology, with many claiming greywater recycling but having rainwater harvesting.

For this reason, a few different water terms are outlined below and in Figure 2:

- Rainwater: this is water collected from the rainfall. It is typically used for flushing toilets and urinals and/or irrigation. It would typically otherwise be directed straight into stormwater drains.
- Greywater: this is water that is used in hand basins and showers, which is collected and used for flushing of toilets and urinals. This water would otherwise go straight to the wastewater network.
- Blackwater: this is another term for wastewater and typically comes from toilets, urinals and kitchen end uses.

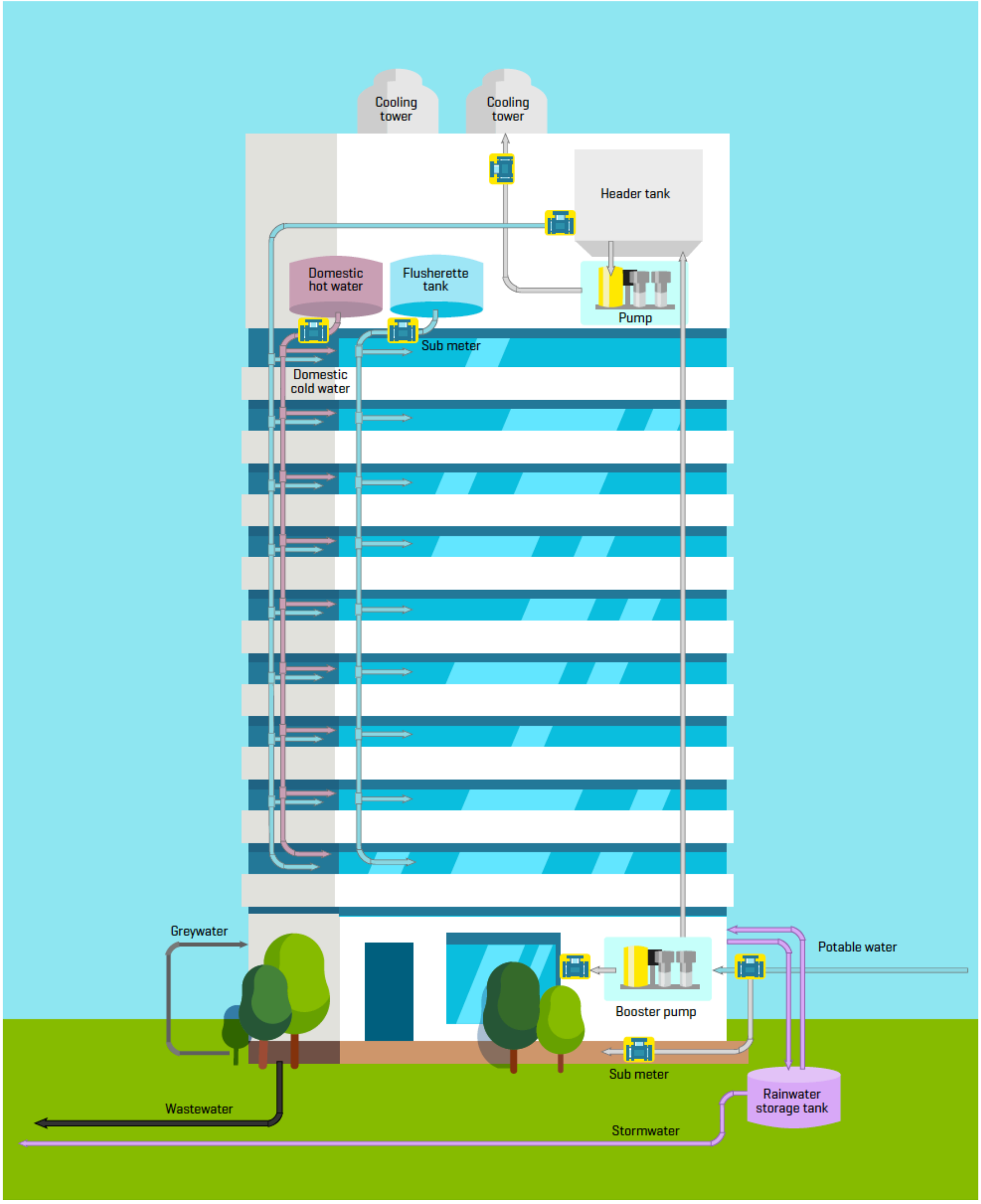


Figure 2. Rainwater, greywater and blackwater in context.

A case study sampling approach was undertaken for the building assessments, where buildings that had the systems were approached. Buildings used for commercial uses were selected for investigation under this research programme. Industrial or intermittent use buildings were not included.

2.2 Assessment method

Ten buildings were initially approved for participation in this research. However, after investigations began, two of the buildings' managers discovered the systems were both currently non-operational and had not monitored any water use for the last 12 months. Therefore, only eight case study buildings formed the remaining research.

These have been coded (by both colour and identifier) to protect their identity. More information on them can be found in Appendix A.

Table 2. Case study building summary.

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

Buildings were initially visited to undertake a water demand audit and revisited on an as-needed basis. The initial visit entailed creating an inventory of every water-using or storage device associated with the building and informally interviewing the building manager for the duration of the site visit.

A clear picture was enabled as to what types of end uses were installed from visiting the water-using devices. Their presence, type, condition/age and use were recorded to contextualise the bottom-up water demand calculations.

Visiting the storage areas provided much more information than can be found in as-built drawings. This included the placement of tanks for rainwater and their access points as well as the location and size of flusher tanks.

In addition to visiting the buildings, the following information was sought from building managers:

- Water bills (if any) for at least 12 months.
- Monitored mains water use for the total building and/or flushing for 12 months.
- Monitored rainwater and/or greywater use for 12 months.
- Monitored rainwater and/or greywater pump on/off schedule for 12 months.
- Floor plans and water reticulation drawings for the building and its systems.
- Contact information for the design teams.
- Feasibility and reasoning for rainwater and/or greywater system inclusion in design.

Further to this, five of the case study buildings were selected to also participate in monthly testing of the rainwater and greywater quality. See section 5 for more information on water quality testing.

3. Capture, storage and demand

This section aims to understand how water is used within the case study buildings in contrast to existing baseline information.

3.1 Water use

The water use within each of the case study buildings has been collated. This was based on historical billed water usage or historical or monitored water use. Rainwater and greywater were monitored over a period of at least 12 months and matched with mains water use, pump on/off schedules and external data such as rainfall. This information is displayed in Table 3 and Figure 3.

In one case, neither billed nor monitored water use was available. Therefore, the total water use was estimated using the water efficiency rating tool (Bint, 2012).

Table 3. Totalised annual water use.

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.

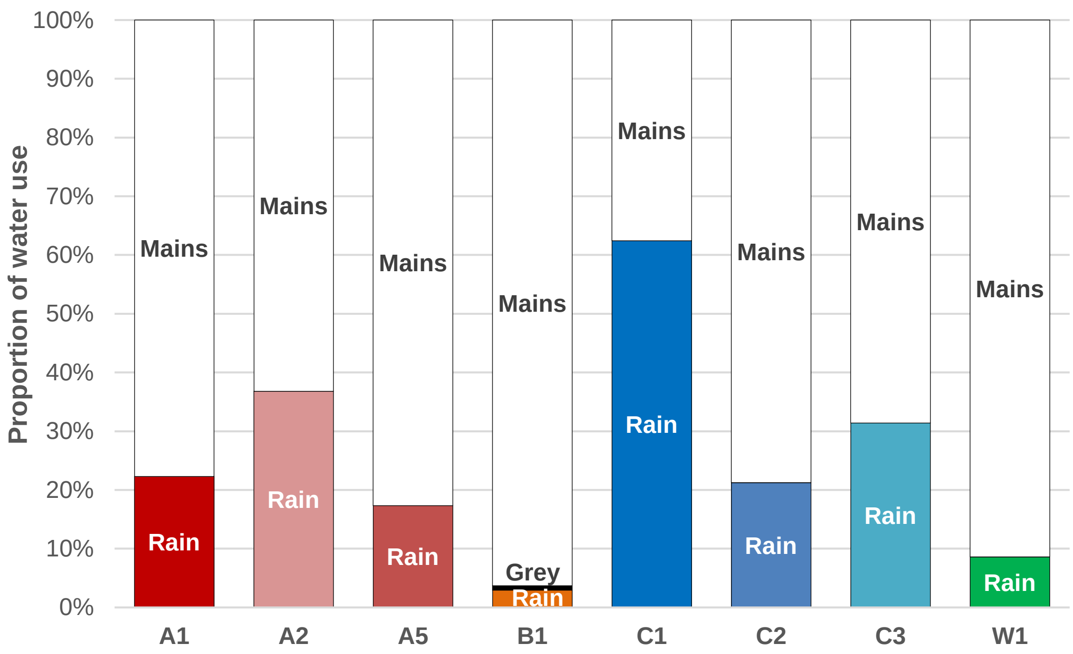


Figure 3. Proportion of total building water use by water type.

Buildings A2, B1 and C1 are all relatively low and wide buildings, while buildings A1, A5, C2, C3 and W1 are taller than they are wide.

Interestingly, building B1 has the largest catchment area but is only servicing a small portion of the water demand. This is largely due to the installation of the rainwater harvesting and greywater recycling system being a retrofit. The expansive retail floor plate means the restroom facilities are located at opposite ends of the floor plate. Therefore, only one male and one female restroom area are connected to the system. The rest are supplied by mains reticulated water only.

A large winter peak in rainwater use was anticipated. However, the peak only appears as a visible detail in the larger users (Figure 4).

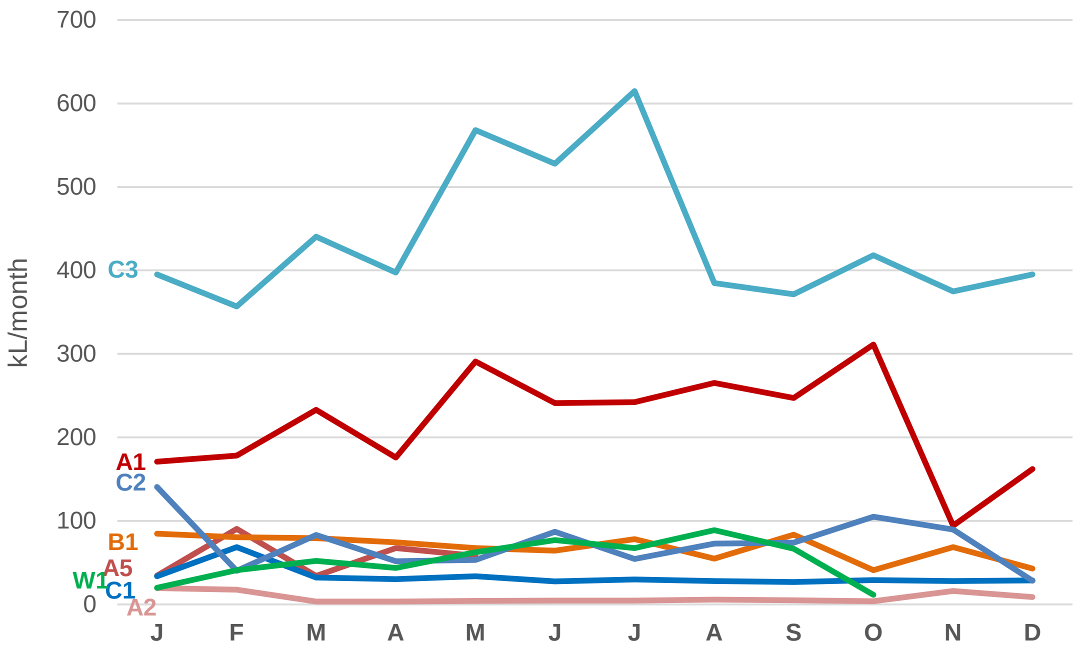


Figure 4. Monitored rainwater and/or greywater by month.

Figure 5 shows the difference between monthly use and the annual monthly average. This enables better visibility of monthly usage.

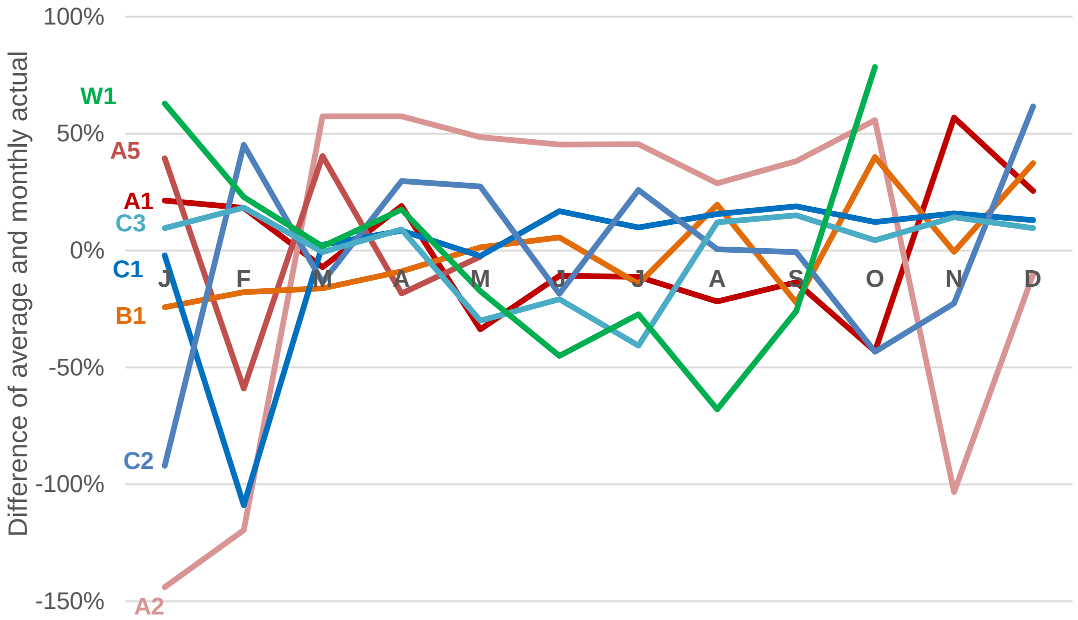


Figure 5. Monitored rainwater and/or greywater use, divergence from average.

This shows that March through September are predominantly well sourced. Buildings A2, C1 and C2, however, appear to have a significant dependency on the mains reticulated network in January and February.

A key takeaway from Figure 5 is the month-by-month consistency in building B1. This is the only building that has a greywater recycling system (which is mixed with harvested rainwater and mains water).

3.2 Water use intensity (WUI)

A common water use metric applied to buildings, which accounts for floor area, is water use intensity (WUI). This is detailed as kilolitres of water per square metre of lettable floor area per year (kL/m^2/year). This has been calculated for the case study buildings as total water used within the building (mains supply + harvested rainwater + recycled greywater). Internationally, net lettable floor area is the benchmark metric. Where there are no published benchmarks for a specific building type in New Zealand, gross floor area benchmarks have been used in their place (Figure 6).

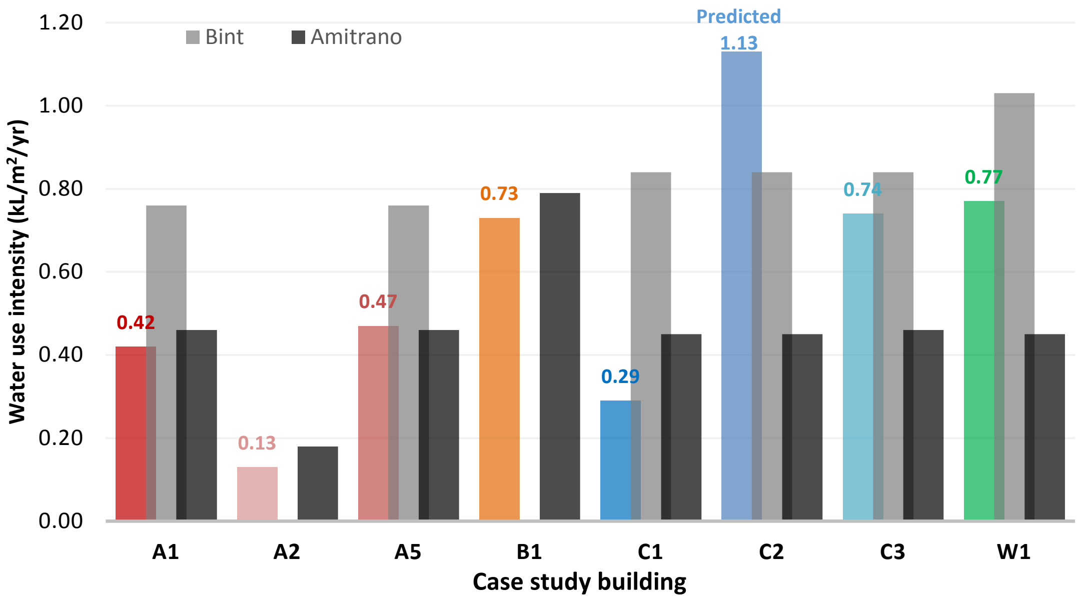


Figure 6. Comparison of building water use intensity against existing benchmarks.

The black (Amitrano et al., 2014) columns are based on gross floor area (GFA), so the WUIs are slightly lower. The grey (Bint, 2012) and coloured (actual) columns are calculated based on net lettable floor area (NLA). This is further detailed in Table 4.

Table 4. Water use intensities.

Type	Case study buildings							
	A1	A2	A5	B1	C1	C2	C3	W1
Benchmark^	0.76[1]	0.18[2]	0.76[1]	0.79[2]	0.84[1]	0.45[2]	0.84[1]	0.45[2]
Mains WUI	0.32	0.08	0.35	0.70	0.11	0.89*	0.51	0.70
WUI	0.42	0.13	0.47	0.73	0.29	1.13	0.74	0.77

* Mains water data was not available. This is a predicted number only.
^ Only the primary benchmark is listed.
[1] Bint (2012) regional net lettable floor area benchmark.
[2] Amitrano et al. (2014) national gross floor area benchmark.

Table 4 shows that, except for building C2, all case study buildings are performing better than the published benchmark. This means that water efficiency was considered in the design before or as well as water conservation via alternative water sources, demonstrating a sustainable design.

3.3 Water end uses

Although all the case study buildings were relatively new (built 2009–2013), there appeared to still be room for water efficiency improvements, particularly with hand basin tapware where high water flows were found.

The Bint (2012) study published an estimated water end use breakdown for 93 large commercial office buildings in Auckland and Wellington. This is used as a baseline measure for the case study buildings to understand how water is used.

The information provided within this section is estimated through using the water efficiency rating tool (WERT) (Bint, 2012).

Figure 7 and Figure 8 show the water end use breakdown colour coded by use type:

- Light is contact, potable water.
- Mid is contact, non-potable water.
- Dark is non-contact, non-potable water – note that HVAC is included here, which is questionable.

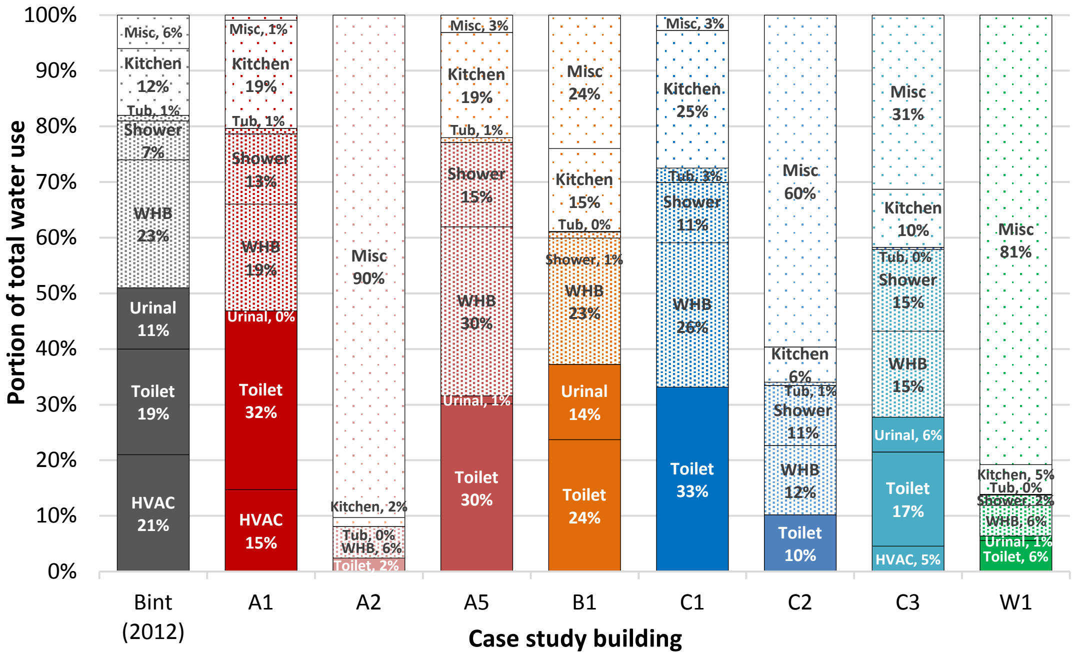


Figure 7. Estimated water end uses in a commercial office building.

This shows that between 2% (A2) and 47% (A1) of the water use is determined non-contact, which could be supplied by recycled greywater. A further 6% (A2) to 46% (A5) of the water use is determined non-potable, which could be supplemented with harvested rainwater. This is, of course, if the supply is available.

As shown in Figure 7, other than A1, A5 and C1 (all office buildings), miscellaneous water use differs significantly by building, which is largely influenced by building type.

A2, C2 and W1 are all educational buildings that house scientific research laboratories. These typically contain many sinks, emergency showers and eye tundishes. B1 is the only retail building, which will have more use in the food court kitchens than the WERT is designed to estimate. C3 is an office building. However, it also contains a decent area of irrigation and a water feature at the rear of the building.

In Figure 8, miscellaneous water use is excluded for the purposes of this analysis and individual known end uses are displayed as a percentage of all known end uses.

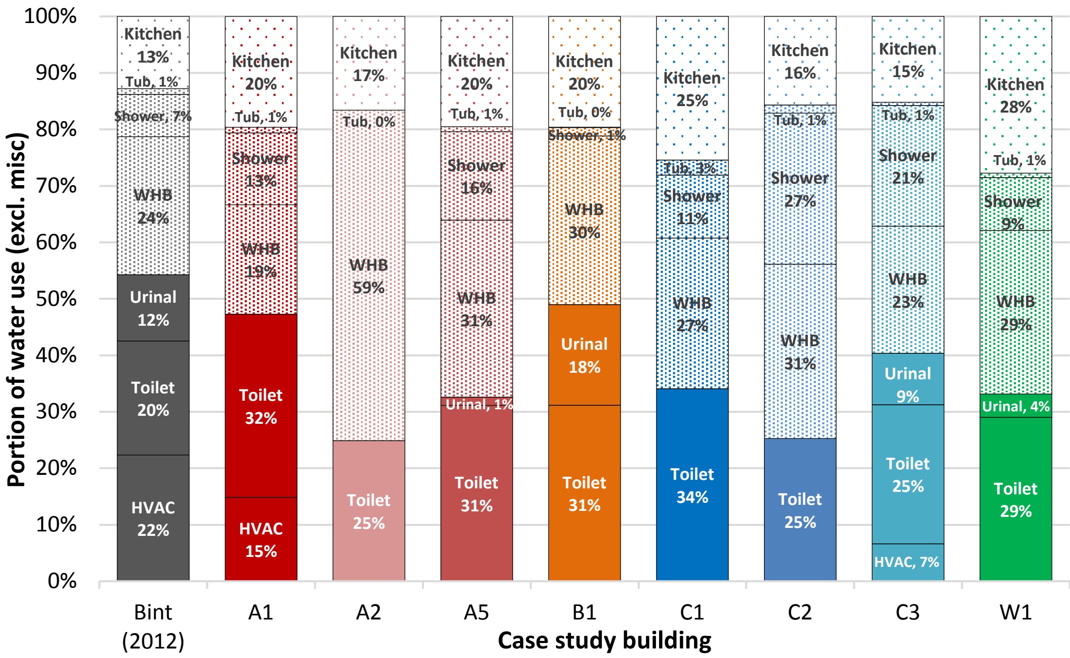


Figure 8. Estimated water end uses excluding miscellaneous water use.

As indicated in the previous section, most buildings appeared to be water efficient. This is also demonstrated through the application of high-rated water efficiency labelling scheme (WELS) end uses and alterative heat rejection systems to water-cooled cooling towers, where possible.

3.4 Water balance

When water balance is investigated at a more granular level, the reliability of the systems can be assessed (Table 5). This is also impacted by tank size calculations that were used in designing the alternative water system.

Table 5. Modelled daily water use summary.

Days per year	Case study buildings							
	A1	A2	A5	B1	C1	C2	C3	W1
Tank size (kL)	24	7	38	20	20	20	185	40
Full demand⁺ met	88	309	219	364	359	205	99	364
	24%	85%	60%	100%	98%	56%	27%	100%
Some demand⁺ met	105	18	53	1	0	48	83	0
	29%	5%	15%	0%	0%	13%	24%	0%
Actual quantity⁺ met	2,661	113	682	866	394	1,780	5,372	641

⁺ Demand refers to specified and designated uses for rainwater/greywater within each building.

As an example, A1 has a 20 kL tank providing 24% of flushing demand. Hypothetically, if the tank had no restriction, an average of 39% of total flushing demand could be met for this building. This specific building has an additional 140 kL temporary stormwater attenuation tank, which would provide this additional buffer over drier spells. Figure 9 shows flushing demand for the case study buildings.

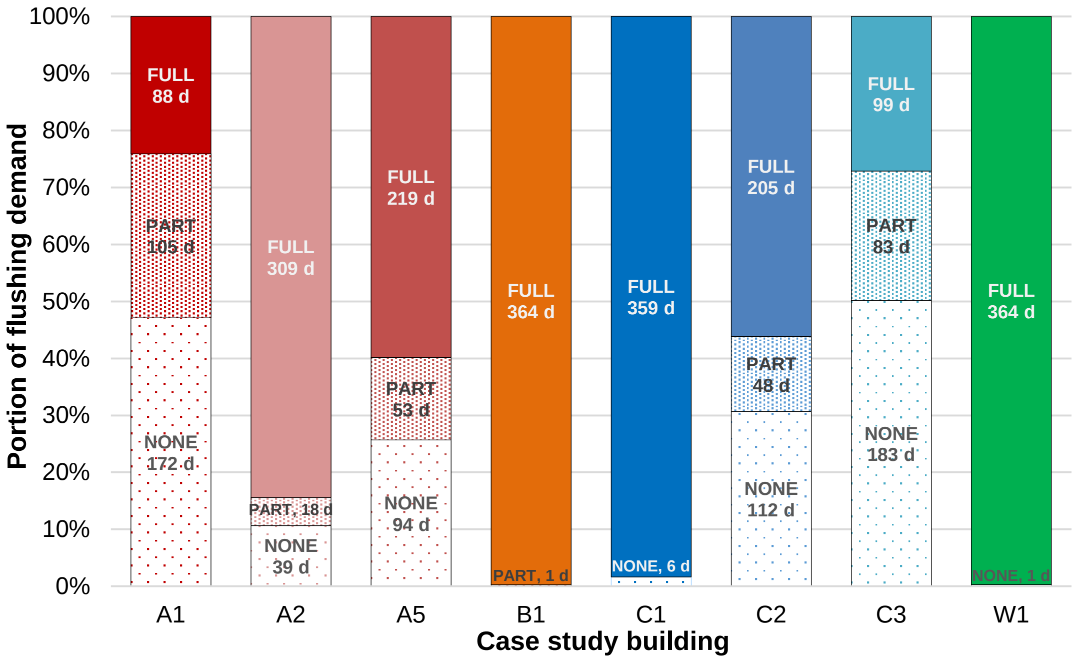


Figure 9. Flushing demand met by rainwater / greywater per day.

Unfortunately, as demand does not always coincide with rainfall, tank size has an impact on the system reliability. Calculations were performed both with the existing tank size capacity as a restriction and with no capacity restriction in place. This enabled the optimum tank size to be determined where the greatest savings could be achieved (see section 4.4).

4. System design and operation

This section describes high-level system requirements, available products and expertise in New Zealand to contextualise the lessons learned from case study buildings. It does not describe the design process or provide hydraulic, plumbing or drainage design guidance in any detail.

The system design of each case study building was interrogated for both well functioning and poorly functioning aspects in relation to design, operation and/or maintenance of the systems and the solutions employed. This information is framed by the five fundamental elements of an integrated rainwater harvesting (Novak, Van Giesen & BeBusk, 2014) or greywater recycling system, which are:

- collection
- conveyance
- filtration and treatment
- storage
- distribution.

Much of the general feedback from the first survey (Bint & Jaques, 2017) suggested there was a lack of education around maintenance requirements for rainwater and greywater systems. The system design dictates the maintenance requirements in both large-scale and small-scale rainwater and greywater systems. In a commercial building context, there are likely to be formal regimes in place to maintain mechanical and hydraulic systems and to protect human health under the Building Act 2004.

4.1 Collection

Collection refers to the location where water is collected – whether that is the roof, building façade, hand basins or another source.

All case study buildings harvested their rainwater from roof areas that had one of three surfaces: profile metal, membrane or rain garden.

In building A5, a rain garden was causing discolouration in the toilet pans. This required some education to building staff around what to expect to avoid a perception of lack of hygiene.

In building C3, a gas vent from a tri-generator was located only a metre or so above the roof line. When visiting the building, staining on the roof was clearly visible. This building also participated in the water quality testing, and no noticeable water quality issues arose from the proximity of the tri-generation vent. There was no mention of any further staining in toilet or urinal pans within the building.

4.2 Conveyance

Conveyance is the transport of water from the collection area to the storage area. It applies to rainwater harvesting and greywater recycling.

The only real lesson here is the distance between collection and storage. Building A1 collected rainwater from the roof on level 27 and transported it to basement level 5 where it was stored. It was then pumped back up to the roof before being gravity fed around the building to its designated end uses.

4.3 Filtration and treatment

There are many filtration and/or treatment options available. These can be classified into debris diversion, first-flush diversion, filtration and treatment.

Debris diversion is usually a leaf strainer above the gutters to prevent wind-collected debris from entering the conveyance system. This was present on most of the case study buildings, both on the roof gutters and as strainers on the booster pumps.

A first-flush diverter removes the first quantity of rainfall from the collection area and disposes of it in the reticulated stormwater network. This is useful for preventing bird droppings and other potential contaminants from entering the system, particularly when there has been an extended period between rainfall events.

Filtration can be in the form of specialised fabric or sand. In the case study buildings, the majority only had strainers on the inlet valve to the booster pumps. In the case of building B1, greywater was transported through a sand filter before ultraviolet treatment and into the mixing tanks where it was mixed with rainwater.

Filtration is one of the largest areas of system failure through lack of maintenance. Most buildings incorporated the rainwater and greywater systems into their regular mechanical and hydronic maintenance check regimes. Buildings C1, C2 and W1 all had a filter of some sort in their system, whether pump strainer or other. These were usually checked monthly and changed annually if no other fault was identified.

Building B1 provided the specified maintenance regime for the greywater system (Table 6).

Table 6. Building B1 maintenance regime.

Annual checks	Monthly checks	Weekly checks
Pumps Float valve and switch Solenoid valves Carbon vent filter Auto backwash filter UV steriliser Water meters Backflow prevention Tank overflow	Inlet strainer on mixer tanks Foot valve Isolation valves Roof outlet strainers	Inlet strainer on pre-treatment greywater tank

Where treatment was present in the case study buildings, it consisted of ultraviolet lamps. Otherwise, no other treatments were encountered.

It was discovered that there was an absence of any New Zealand product and/or system appraisals or certification of rainwater and greywater technologies for use in buildings. Throughout the duration of this research, product manufacturers and retailers, local councils, hydraulic engineers and property developers have expressed their concern and/or frustration. Building consent authorities need to be satisfied “on reasonable grounds” that the proposed work will meet the requirements of the New Zealand Building Code (Ministry of Business, Innovation and Employment, 2016). This means that unappraised or certified technologies or technologies without existing international precedents to demonstrate success may not meet this requirement.

4.4 Storage

Water storage is sometimes regulated by local council requirements and usually for the maximum duration of storage without stagnation. New Zealand legislation also requires backflow prevention devices and has specific material requirements for potable water.

These are the key lessons, operational challenges and observations from the case study buildings:

- Structural requirements from the total load of a full rainwater tank mean they needed to be in basement regions. No staged tanks were encountered throughout the case study buildings in this study. In some older buildings identified in Bint's (2012) work, staged distribution tanks were observed.
- Storage tanks were either concrete under ground or plastic above ground. Unenclosed tanks exist but are not recommended due to health and safety concerns.
- Storage space is in competition for lettable parking spaces.
- Location and automation of rainwater and greywater to mains switchover technology (and vice versa):
  - Building A5 had issues with the automation, which meant location for maintenance access also became an issue.
  - Building C3 had a manual switch-over in the basement. This meant the building manager had to make their way down to the basement and switch from mains supply to rainwater or vice versa. An automated system has since been installed.
- Monitoring of the storage system as well as collection, distribution and overflow systems.
- Only buildings B1 and W1 had an emergency supply draw point installed. Resilience was a key factor in the decision to install the rainwater or greywater system. However, in times of the pumps not working during a fault, it is unclear how the water will be available for emergency use without a significant health and safety hazard.
- Size and designed capacity of the tanks in relation to the building size and use. Table 7 uses an unrestricted tank size to demonstrate the additional water savings possible. This only considers the monitored data period.

Table 7. Current tank size yield versus unrestricted tank size yield.

	A1	A2	A5	B1	C1	C2	C3	W1
Current tank size (kL)	24	7	38	20	20	20	185	40
Actual yield (kL/yr)	2,661	113	682	866	394	1,780	5,372	641
Unrestricted tank size (kL)	106	532	190	40,288	680	397	589	942
Estimated yield (kL/yr)[1]	2,661	989	1,110	46,158	832	841[2]	2,285[2]	1,489

[1] Over 1 year only – greater cumulative values are possible over multiple years.
[2] Actual yield exceeds modelled estimated maximum yield. This may be due to mains water top-up in the tank.

Table 7 highlights the amount of collected water overflowing into the stormwater or wastewater network. For building B1 specifically, the annual savings available are if the rainwater and greywater could be used for greater purposes than just flushing of one toilet block. This is primarily due to a very large building footprint of only 1 storey. However, an unrestricted tank size is grossly unrealistic.

In only one building was an additional stormwater attenuation tank identified. However, water in this tank could not be drawn for use within the building. Rather the contents were slowly released into the stormwater system to reduce the impact of a heavy rainfall event on the reticulated infrastructure.

4.5 Distribution

The reticulation and pumping requirements are a core part of hydraulic design in a commercial building. Lilac piping is adopted through AS/NZS 3500 *Plumbing and drainage* to indicate the non-potable supply.

Mains water typically enters the building at ground or basement level and is transported up to roof tanks for distribution. As observed in the case study buildings, rainwater is collected at roof level, transported to basement storage before being transported back to roof tanks for distribution.

The water in A1, for example, is collected on level 23. The collected rainwater is then gravity fed and stored in an underground concrete tank within the basement (five levels below ground). The water is then pumped back up to level 22 and gravity fed down through the flusher tank distribution line.

There are two impacts from this design:

- The additional energy required to pump the rainwater back up to where it came from initially.
- Pumps may not have bees specified correctly and therefore the flow on upper floors was not enough for complete toilet flushing.

There are structural issues surrounding the placement of large water storage tanks, which is the core reason for the additional transportation and pumping of rainwater (see section 4.4).

Sub-metering was present in almost all case study buildings at varying degrees of monitoring coverage, data storage and data analysis. One building, A2, had no sub-metering or water monitoring in place. Buildings A1 (19 water meters, monthly manual readings) and C3 (71 water meters, daily automated readings) are the best examples of water monitoring. However, only building A1 analysed and used the data to understand the operation and performance of their building systems.

Overall, there is a lack of any consistent New Zealand design guidance. However, there are many lessons observed in these eight case study buildings that can be used to form good-practice guidelines for the design, operation and maintenance of rainwater and/or greywater systems in commercial buildings.

5. Water quality and health risk

This section addresses the concerns identified in Bint & Jaques (2017) where water quality, waterborne disease and health were the primary concerns with rainwater harvesting and/or greywater recycling systems.

Five of the case study buildings had their water quality examined between December 2015 and November 2016 (Table 8). Samples were collected from their storage tanks every month by BRANZ and sent to ESR within 24 hours of collection.

This section describes the findings from ESR's water quality and health risk assessment (Siggins & Cressey, 2017).

Table 8. Characteristics of sampled buildings.

	A2	B1	C1	C3	W1
System	Rainwater	Greywater + rainwater	Rainwater	Rainwater	Rainwater
Treatment		Sand + UV			
Building use	Office/ warehouse	Retail	Education/ service	Office	Education/ service
Location	Urban	Provincial	Provincial	Urban	Urban

The information presented here summarises the findings. Detailed water quality results for individual buildings can be found in Appendix B.

5.1 Rainwater quality

Four of the case study buildings – A2, C1, C3 and W1 – had their rainwater quality tested every month over one year. All samples were taken prior to treatments (if any) in two 300 mL containers per building.

Published literature was used as a comparative measure to inform the sampled findings and the most appropriate indication of acceptable levels of microbial and chemical contaminants (see Table 9). For this, the New Zealand drinking water standards were used (Ministry of Health, 2008).

Most of the values from chemical analysis are less than the current New Zealand drinking water maximum acceptable values or guideline values.

Lead, nickel, iron and zinc limits were all exceeded at various times throughout the monitoring period. These detections coincided with construction activities immediately adjacent to the rainwater collection area and thus is hypothesised to have caused an increase in detected metals.

However, all samples are well below the modified values, which were recalculated to reflect the lower volume of toilet flush water expected to be ingested compared to drinking water.

Table 9. Summary of key inorganic chemicals in rainwater samples.

A2, C1, C3, W1	Sampled range (mg/L)	Maximum acceptable value^ (mg/L)	Modified maximum acceptable value* (mg/L)
B (boron)	0.001–0.094	1.4	930
Cd (cadmium)	0.0004–0.001	0.004	2.7
Cu (copper)	0.0006–0.086	2	1,300
Pb (lead)	<0.003–0.145	0.01	6.7
Mn (manganese)	<0.0001–0.058	0.4	270
Ni (nickel)	<0.001–0.368	0.08	53
NO_3^- (nitrate)	<0.1–1.2	50	33,000
NO_2^- (nitrite)	<0.2	0.2 (long term) 3 (short term)	130 (long term) 2,000 (short term)
A2, C1, C3, W1	**Sampled range (mg/L)**	**Guideline value^ (mg/L)**	**Modified guideline value* (mg/L)**
Al (aluminium)	<0.002–0.038	0.1	67
NH_4^+ (ammonium ion)	<0.1–1.5	1.5	1,000
Hardness as $CaCO_3$	2.3–39.5	200	130,000
Fe (iron)	<0.0007–7.2	0.2	130
Na (sodium)	1.2–39.0	200	130,000
Zn (zinc)	0.01–4.1	1.5	1,000

^ For drinking water.
*New Zealand maximum acceptable values and guideline values recalculated using an ingestion volume of 3 mL (0.003 L) rather than 2 L (Siggins & Cressey, 2017).

The case study building rainwater was also analysed for microbiological contaminants (see Table 10). Three were targeted: *Escherichia coli* (*E. coli*), an indicator of faecal contamination, and *Campylobacter* spp. and *Salmonella* spp., which are known human pathogens.

Table 10. Summary of microbiology in rainwater samples.

A2, C1, C3, W1	*Escherichia coli* MPN/100mL	*Campylobacter* spp. MPN/100mL	*Salmonella* spp. MPN/100mL
Guideline limit	1	Not available	Not available
Detection limit	1	2	2
Sampled range	0–8,500	0	0–4
Samples detected	18/45	0/45	1/45

It should be noted that 11 of the 18 samples with *E. coli* detected were from the same building, C3. This particular building did not have an enclosed tank, which is the only distinction between the other buildings sampled.

These chemical and microbial results are reasonably consistent with previous New Zealand studies (Siggins & Cressey, 2017). They and show that, with correct design and maintenance, a high level of water quality can be maintained before treatment or filtration.

5.2 Greywater quality

Only one case study building with greywater recycling was identified in New Zealand. This building, B1, was sampled both before and after filtration and treatment.

The sampling was split into two types. Monthly samples were taken both pre-treatment and post-treatment in two 300 mL containers as per the rainwater samples. This sample was tested for the same inorganic chemical and microbial parameters as the rainwater samples.

Of the inorganic chemicals determined in the greywater samples, with the exception of ammonia, only aluminium exceeded the guideline value in a single sample (see Table 11). However, it should be noted that the guideline values are in New Zealand drinking water standards for aesthetic water qualities only.

Table 11. Summary of key inorganic chemicals in greywater samples.

B1	Sampled range (mg/L)	Maximum acceptable value^ (mg/L)
B (boron)	0.008–0.072	1.4
Cd (cadmium)	0.001	0.004
Cu (copper)	0.02–0.26	2
Pb (lead)	0.004–0.008	0.01
Mn (manganese)	0.0001–0.0089	0.4
Ni (nickel)	0.003–0.042	0.08
NO_3^- (nitrate)	0.1–9.6	50
NO_2^- (nitrite)	0.02–0.03	0.2 (long term) 3 (short term)
B1	**Sampled range (mg/L)**	**Guideline value^ (mg/L)**
Al (aluminium)	0.004–0.11	0.1
NH_4^+ (ammonium ion)	0.2–6.8	1.5
Hardness as $CaCO_3$	2.9–22.3	200
Fe (iron)	0.004–0.13	0.2
Na (sodium)	3–28	200
Zn (zinc)	0.01–0.29	1.5

^ For drinking water.

For the microbial analysis, *E. coli* was found in the pre-treatment sample in low levels during 3 months (see Table 12). No *E. coli* or other microbial detections occurred post-treatment.

Table 12. Summary of microbiology in monthly greywater samples.

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

Quarterly samples were taken before treatment only, in 20 1 L containers. This sample was tested for *Giardia* spp., *Cryptosporidium* spp. and culturable adenovirus.

As above, no pathogens were detected in the quarterly greywater samples (see Table 13).

Table 13. Summary of microbiology in quarterly greywater samples.

B1	*Giardia* spp. Cysts/10L	*Cryptosporidium* spp. Oocysts/10L	Culturable adenovirus IU/L
Reported literature	0	0	-
Detection limit	1	1	1
Sampled range	0	0	0
Samples detected	0/4	0/4	0/4

Overall, the quality of greywater in this single case study building was better than expected. More work is required to make this statement more representative, through investigation of a much larger sample.

5.3 Health risk assessment

There is little to no data available regarding associated health risks from greywater recycling systems in either New Zealand or internationally. This is expected, given only one commercial building in New Zealand was identified to have a system in operation.

To determine the level of health risk within the case study buildings, a model was developed to determine the individual infection risk. This uses the *Salmonella* spp. results from Table 10, as it was the only pathogen (infrequently) detected in the study. There is insufficient information to infer a relationship between indicator organism concentrations (such as *E. coli*) and concentrations of human pathogens for New Zealand roof-collected rainwater.

The simulation suggested a very low level of risk of *Salmonella* spp. infection from flushing toilets and urinals with rainwater. If toilet users ingest flush water at every usage (worst-case scenario), the probability of *Salmonella* spp. infection was determined to be approximately a one in a million risk.

6. Feasibility assessment

This section assesses the full costs associated with the design, installation, operation and maintenance of rainwater harvesting and greywater recycling systems. Participation of the case study buildings also meant providing information on capital and operating costs.

6.1 Economic analysis

Some difficulties were encountered with costing information. The building managers did not necessarily have a detailed cost breakdowns to identify the system's capital costs. For those that were unable to provide this information, an independent hydraulic engineering firm was engaged to cost the systems for the purposes of this study.

System details are shown in Table 14.

Table 14. System cost and description.

Building	Initial cost (NZD)	Tanks (L)	Description
A1	$49,300	24,000	Concrete tanks in foundation of building. 140,000 L attenuation to minimise the stormwater building load on the network. BMS interface on tank, pumps and filters. Estimated 0.04% of total cost.
A2[1]	$13,000	7,000	Concrete tank under car parking area. No BMS interface.
A5[1]	$29,260	38,000	Concrete tank under external accessway. BMS interface.
B1	$87,852	25,300	Bladder tank under carpark ramp + mixer tanks in locked storage area.
C1[1]	$22,000	20,000	Above-ground poly tanks. Minimal BMS interface.
C2	N/A	20,000	Underground concrete/fibreglass tank. Minimal BMS interface.
C3[1]	$48,425	185,000	Basement concrete tank with top 500 mm open.
W1[1]	$30,200	40,000	Poly tanks in basement car park. Minimal BMS interface. Estimated 0.08% of total cost.

[1] These buildings were costed at today's prices due to unavailability of costing information at the time of build.

The study also attempted to look at the increased energy use due to treatment and pumping. However, very little information was monitored at the detail required.

The maintenance and energy costs were estimated by building management, and the energy consumption was estimated using the size and number of pumps and their respective monitored on/off schedule.

Table 15 details the financial information collected and calculated for the case study buildings.

The key piece of information here is the benefit-cost column. A figure ≥1.00 is a strong indicator that the system is financially viable over a 25-year period.

Table 15. Cost-benefit information.

Building	Capital cost	Annual O&M	2016 savings	Payback period	Benefit-cost 25 year	IRR 25 year	Install date
A1	$49,300	$1,000	$14,862	3.32 y	3.04	25.32%	2009
A2[1,2]	$13,000	$1,500	$629	20.66 y	0.25	N/A	2013
A5[1]	$29,260	$4,300	$3,809	7.68 y	0.58	N/A	2009
B1	$87,852	$700	$1,378	63.75 y	0.19	-7.57%	2013
C1[1,3]	$22,000	$400	$0	-	-	-	2009
C2[3]	N/A	$400	$0	-	-	-	2010
C3[1,3]	$48,425	$500	$0	-	-	-	2010
W1[1]	$30,200	$0[4]	$1,490	20.27 y	0.62	1.38%	2010

[1] Costed at 2017 price due to unavailability of costing information at the time of build.
[2] 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] Building management state that OpEx is included in hydraulic O&M with minimal expenditure.

Another key number is the payback period. As a general rule of thumb, a payback period of 15 years or less on such a system would be considered viable. However, discussions with attendees of the Facility Managers Association of New Zealand (FMANZ) Summit in 2015 suggested that a maximum payback period of between 3 and 5 years was desirable.

This would maximise the likelihood that developers would approve the inclusion of such a system in the building design. The longer the payback period, the less likely that a system would be funded without significant non-financial benefits or other compulsion (for example, council requirements) supporting the business case.

Table 15 suggests that only those in Auckland have a payback period less than 5 years and a benefit-cost ratio greater than 1. This is primarily due to the presence of volumetric water and wastewater tariffs.

The Bint (2012) study found that office buildings in Auckland used, on average, less water per net lettable square metre than Wellington. The reverse was hypothesised based on outdoor temperature and humidity conditions (influencing the efficiency and therefore water use in cooling towers and irrigation systems).

Bint (2012) found that the Auckland buildings used less water per square metre for two main reasons:

- Universal metering and water charges in residential properties perpetuated water conservative behaviours in the workplace.
- Volumetric wastewater tariffs provided a greater financial incentive to reduce water consumption.

This finding has the same effect on the decision to install rainwater harvesting and greywater recycling systems.

The Auckland water and wastewater tariff system has been applied on the Bay of Plenty, Wellington and Canterbury buildings for the purposes of this analysis. This enables the true effect of volumetric wastewater tariffs on consumption behaviour to be assessed.

Table 16 shows that all metrics have vastly improved with the application of volumetric wastewater tariffs.

It also indicates that almost all the buildings with rainwater harvesting systems would be approved based on the benefit-cost ratio but not when it comes to the 5-year payback principle provided by the FMANZ Summit discussions.

Table 16. Cost-benefit information using Auckland water and wastewater tariffs.

Building	Capital cost	Annual O&M	2016 savings	Payback period	Benefit-cost 25 year	IRR 25 year	Install date
A1	$49,300	$1,000	$14,862	3.32 y	3.04	25.32%	2009
A2[1,2]	$13,000	$1,500	$629	20.66 y	0.25	N/A	2013
A5[1]	$29,260	$4,300	$3,809	7.68 y	0.58	N/A	2009
B1	$87,852	$700	$4,206	20.89 y	0.57	-0.01%	2013
C1[1]	$22,000	$400	$2,202	9.99 y	1.03	2.06%	2009
C2	N/A	$400	$5,217	N/A	N/A	N/A	2010
C3[1]	$48,425	$500	$30,003	1.61 y	7.85	39.55%	2010
W1[1]	$30,200	$0[3]	$3,582	8.43 y	1.50	10.02%	2010

[1] Costed at 2017 price due to unavailability of costing information at the time of build.
[2] Actual costs associated with the rainwater system redesign are included in the capital cost.
[3] Building management state that OpEx is included in hydraulic O&M with minimal expenditure.

In a purely financial analysis, the building with greywater recycling and rainwater harvesting is not quite feasible.

This means that a significant non-financial case or compulsion would also be needed to secure investment.

This leaves the question remaining: what were the drivers for including rainwater harvesting and/or greywater recycling systems in other areas than Auckland if they were not financial?

6.2 Non-financial benefits

From the financial analysis above, it is clear that a value case is needed to emphasise the non-financial benefits or to quantify them, particularly outside Auckland.

Where a benefit-cost ratio is close to but below 1.00, the non-financial benefits may be enough to convince the decision makers to proceed.

Bint & Jaques (2017) found the main drivers for installing a rainwater and/or greywater system were cost, sustainability, impact on supply and resilience, primarily from a perspective of saving water and helping the environment.

Table 17 is a summary of the reasoning for installing rainwater harvesting and greywater recycling systems within the case study buildings.

Interestingly, only building W1 had a stated future financial benefit, while almost all buildings have used long-term sustainability and/or resilience as the key decision.

Table 17. Feasibility case for rainwater / greywater systems in case study buildings.

<table>
<tr><th>Building</th><th>Decision to install</th><th>Green Star NZ</th></tr>
<tr><td>A1</td><td>Green Star NZ.</td><td>5 star</td></tr>
<tr><td>A2</td><td>Property owner's belief in future of sustainability.</td><td>Guidance used</td></tr>
<tr><td>A5</td><td>Green Star NZ and long-term sustainability agenda.</td><td>5 star</td></tr>
<tr><td>B1</td><td>Sustainability and resilience profile – set targets for energy, water, waste and emissions reductions long term.</td><td>Guidance used</td></tr>
<tr><td>C1</td><td rowspan="2">Long-term sustainability and resilience planning.
"All new buildings shall be designed to comply with the intent to achieve sufficient points towards obtaining a 5 star Green Star NZ rating on a self-assessed basis of the Green Star NZ Education and/or Office tool … Buildings are to be designed to achieve the equivalent energy efficiency of a 4 Star NABERS commercial building (Energy) whole building rating (223kgCO_2/ m^2/annum)." (University of Canterbury, 2016)</td><td>5 star</td></tr>
<tr><td>C2</td><td>Guidance used</td></tr>
<tr><td>C3</td><td>Green Star NZ beyond best practice and leadership.</td><td>6 star</td></tr>
<tr><td>W1</td><td>Future financial and resilience reasons.</td><td>Guidance used</td></tr>
</table>

This shows that the Green Star NZ initiative, whether certification is pursued, is providing guidance on alternative water sources. It is also having an impact on the uptake of rainwater harvesting systems at the very least.

Other such non-financial benefits include those indicated in Bint & Jaques (2017) and are listed below. Many of these have significant benefits to the water supplier:

- Building resiliency – particularly post-disaster resilience.
- Improved water quality entering the wastewater network.
- Reduction in demand for mains potable water.
- Environmental benefits from using untreated water for non-potable uses.
- Reduction in wastewater returned to the network (for greywater recycling).
- Delayed infrastructure requirements, especially for regions like Auckland.

Therefore, the value case for alternative water sources in commercial buildings should include such things as:

- reliability and consistency of reliability of supply (for greywater recycling systems)
- resiliency
- water and wastewater charge reductions and potentially development contributions
- competitive advantage and premium rents for buildings and building space.

7. Summary

The assessment of eight case study buildings across New Zealand that had a rainwater harvesting and/or greywater recycling system in operation has been conducted. The case study buildings proved to be better than the average commercial building in terms of water efficiency as measured by the total building water use intensities all falling below the median water use benchmark. However, only two of the case study buildings were using the water systems to their full potential. The others have significant underutilised opportunity to expand their rainwater and/or greywater systems to increase system efficiencies.

Several design lessons were observed through the site investigations, as-built documentation, discussions with building managers and users and analysis of monitored water data. The three biggest design lessons are:

- user friendly monitoring and straightforward switchovers from rainwater and/or greywater to mains water
- better storage and distribution design has the potential to significantly reduce additional pipe, pumping and ongoing energy costs
- improved education for building managers and clearly laid out long-term maintenance plans and/or schedules.

The financial feasibility is found to be almost entirely dependent on volumetric water and wastewater tariffs. The case study buildings showed that, despite having poor financial payback periods in their own regions, using an Auckland-based tariff structure meant the systems became financially feasible. This is also demonstrated in the tariff impact of water use and efficiency in previous New Zealand studies (Bint, 2012). The charging mechanisms (i.e. volumetric wastewater tariffs) outside Auckland are not providing the financial drivers for buildings to use less water or become less reliant on the mains reticulated networks.

Non-financial or intangible benefits have not been quantified in this study. Other secondary, indirect or non-financial benefits should be further quantified to present the full value case. These include:

- individual resilience during post-disaster fault to water network
- reduction in chemical treatment of waste entering the wastewater network
- potentially delayed infrastructure requirements by reduction in mains potable water and wastewater quantities.

This water quality study found that there is likely to be little or no potential human health risk surrounding the use of rainwater or greywater for toilet and urinal flushing. However, due to the small number of buildings included in this study, this work cannot be used in a representative manner.

7.1 Future work

The findings from this research have raised several questions on where to next. Below is a list of recommendations for future work in this area.

- Design or good practice guidelines for rainwater and greywater systems in buildings.

- System awareness, maintenance and operation education and guidance for designers, operators and facilities maintenance.
- Larger sample size for both rainwater and greywater quality to determine public health risks.
- Quantification of secondary or indirect financial and non-financial benefits from installing rainwater and/or greywater systems in commercial buildings.

Through presenting the findings of this baseline feasibility study, many ideas, concerns and recommendations have been collated for future research work. These are included in the above list.

For more information and participation opportunities in future work, please visit the project webpage at www.branz.co.nz/rwhgwr.

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Appendix A: Case study buildings – additional information

Descriptor	A1	A2	A5	B1	C1	C2	C3	W1
BUILDING CHARACTERISTICS								
Region	Auckland	Auckland	Auckland	Bay of Plenty	Canterbury	Canterbury	Canterbury	Wellington
Building use	CO	CO-IW	CO	CR	E-CO	E-IS	CO	E-IS
Net lettable floor area (NLA)	28,663 m^2	2,440 m^2	9,366 m^2	32,323 m^2	2,143 m^2	7,395 m^2	23,000 m^2	9,727 m^2
Gross floor area (GFA)	23,500 m^2	2,440 m^2	9,366 m^2	35,367 m^2	2,333 m^2	8,402 m^2	23,000 m^2	10,511 m^2
Footprint	2,041 m^2	1,131 m^2	2,582 m^2	35,367 m^2	1,167 m^2	1,400 m^2	3,801 m^2	1,301 m^2
Roofing material	Profiled metal	Profiled metal	Gravel/garden	Profiled metal	Membrane	Profiled metal	Profiled metal	Profiled metal
Storeys	24	2	7	1	2	6	8	7
Occupants	1,933	8	750	(visitors) 11,000	214	500	1,434	248
WATER SYSTEM CHARACTERISTICS								
Water system	Rainwater	Rainwater	Rainwater	Rain + grey	Rainwater	Rainwater	Rainwater	Rainwater
Uses	Flushing, irrigation	Flushing, irrigation, warehouse	Flushing, irrigation	Flushing	Flushing	Flushing	Flushing, irrigation, water feature	Flushing
Collection area	2,041 m^2	9,691 m^2	969 m^2	35,367 m^2	1,167 m^2	1,178 m^2	3,903 m^2	1,301 m^2
Run-off coefficient	0.95	0.95	0.40	0.95	0.80	0.95	0.95	0.95
Tank	Concrete, underground, mains top-up	Concrete, underground, switchover	Concrete, underground, switchover	Poly mixer tanks, above ground, mains top-up	Poly tanks, above ground, mains top-up	Concrete, underground, mains top-up	Concrete, basement, switchover	Poly tanks, basement, switchover
Tank size	24,000 L	7,000 L	38,000 L		20,000 L	20,000 L	185,000 L	40,000 L
Filtration	-	5 + 50µm filters	Sand	Sand	Flushing filters	-	-	-
Treatment	UV	-	UV (disused)	UV	-	-	-	-
Installation	2009, new build	2013, new build	2009, new build	2013, retrofit	2009, new build	2010, new build	2010, retrofit	2010, new build
Decision to install	Green Star NZ	Long-term sust	Green Star NZ	Long-term sust	Long-term sust	Long-term sust	Green Star NZ	Long-term sust
WUI	kL/m^2/yr	kL/m^2/yr	kL/m^2/yr	kL/m^2/yr	kL/m^2/yr	kL/m^2/yr	kL/m^2/yr	kL/m^2/yr
COST INFORMATION								
Capital cost	$49,300	$13,000	$29,260	$87,852	$22,000	N/A	$48,425	$30,200
Operation and maintenance cost	$1,000	$1,500	$4,300	$700	$400	$400	$500	$0
Water tariff (2016/17)	$1.444/kL	$1.444/kL	$1.444/kL	$1.83/kL	$0.73/kL after allocation	$0.73/kL after allocation	$0.73/kL after allocation	$2.323/kL
Wastewater tariff (2016/17)	$4.359/kL	$4.359/kL	$4.359/kL	Rates	Rates	Rates	Rates	Rates
Annual water savings	$14,862	$629	$3,809	$1,378	$0	$0	$0	$1,490
Benefit-cost (25 yr)	3.04	0.25	0.58	0.19	No payback#	No payback#	No payback#	0.62
Internal rate of return (25 yr)	25.32%	N/A	N/A	-7.57%	No payback#	No payback#	No payback#	1.38%
Payback period	3.32 yr	20.66 yr	7.68 yr	63.75 yr	No payback#	No payback#	No payback#	20.27 yr

No payback calculated as there is no volumetric charge for water in this region if allocation is not exceeded (the allocated was not exceeded).

Appendix B: Water quality testing results carried out by ESR

Anything in red is outside the guideline limits (either above or below).

A2 (PRE-TREATMENT)	Guide*	Limit^	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
MICROBIOLOGY (MPN/100mL)														
E. coli (MPN/100mL)	1	1	BDL	BDL	BDL	BDL	BDL	16	8	29	BDL	BDL	BDL	BDL
Salmonella spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Campylobacter spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
CHEMISTRY														
pH	7–8		6.44	6.42	7.79	7.09	7	7.04	6.85	7.08	6.95	7.02	6.57	6.61
TSS (total suspended solids)			0	1.5	0	0.4	0	0.5	0	0.4	0.5	1.00	0.50	0.50
NH_4^+ (ammonium ion)	1.5	0.1	0.16	0.14	0.14	0.23	0.12	0.4	BDL	BDL	BDL	0.00	0.03	0.02
NO_3^- (nitrate)	50	0.1	0.14	BDL	0.24	0.32	0.27	0.03	0.192	0.115	0.115	0.16	BDL	0.14
NO_2^- (nitrite)	3	0.2	BDL	BDL	BDL				BDL	BDL	BDL	BDL	BDL	BDL
N (total nitrogen)			0.25	3.3	0.57	0.35	0	0.53	0.794	0.28	0.366	BDL	BDL	BDL
P (total phosphorus)			BDL	0.002	BDL	0.003	BDL	0.001	BDL	0.007	0.006	BDL	0.006	BDL
Na (sodium)	200	0.001	1.243	2.009	2.397	5.058	3.571	8.406	8.422	1.779	4.353	10.228	4.399	2.487
Ca (calcium)		0.003	1.349	BDL	7.454	3.775	4.454	6.128	4.501	2.565	2.132	3.280	2.081	1.229
Mg (magnesium)		0.0004	0.147	0.132	0.199	0.256	0.279	0.518	0.907	0.206	0.566	1.031	0.465	0.251
SAR			0.357	1.185	0.327	0.915	0.599	1.168	1.47	1.71	0.33			
Cu (copper)	2	0.0006	0.001	0.001	0.005	0.018	0.004	0.004	0.003	0.002	0.003	0.001	0.001	BDL
Zn (zinc)	1.5	0.00015	0.376	0.136	0.069	0.193	0.199	0.216	0.262	0.067	0.151	0.128	0.129	0.101
Al (aluminium)	0.1	0.0021	0.005	0.005	BDL	0.005	0.008	0.009	0.011	0.015	0.007	0.013	0.012	0.006
B (boron)	1.4–2.4	0.0006	0.01	0.068	0.05	0.017	0.01	0.052	0.005	0.01	0.007			
Cd (cadmium)	0.003–0.004	0.0003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.0005	BDL	0.0004
Fe (iron)	0.2	0.0007	BDL	0	BDL	BDL	BDL	0.001	0	BDL	BDL	BDL	BDL	BDL
K (potassium)		0.007	0.11	0.34	0.594	0.565	0.457	0.91	1.189	0.538	0.596	0.905	0.554	0.503
Mn (manganese)	0.4	0.00008	0.002	0.001	0.002	0.003	0.002	0.004	BDL	BDL	BDL	0.002	0.003	0.002
Ni (nickel)	0.07–0.08	0.001	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb (lead)	0.01	0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.005	0.007
S (sulphur)	250	0.0072	0.264	0.18	0.562	0.618	0.441	0.939	0.893	0.233	0.509	0.785	0.376	0.186
NOTES														
Activities														< - Adjacent construction site - >

* (Ministry of Health, 2008). ^ Detection limit. BDL: below detection limit.

B1 (PRE-TREATMENT)	Guide	Limit^	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
MICROBIOLOGY														
E. coli (MPN/100mL)	0–10^7	1	BDL	BDL	2.4×10^3	BDL	BDL	BDL	BDL	BDL	6	BDL	7	BDL
Salmonella spp. (MPN/100mL)	0–10^4	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Campylobacter spp. (MPN/100mL)	0	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Giardia (cysts/10L)$^+$	0	1			BDL			BDL			BDL			BDL
Cryptosporidium spp. (ooscyts/10L)$^+$	0	1			BDL			BDL			BDL			BDL
Culturable adenovirus (IU/L)$^+$		1			BDL			BDL			BLD			BDL
CHEMISTRY														
pH	5–10[ab]		6.24	6.38	6.44	6.49	6.32	6.49	6.45	6.26	6.34	6.35	5.95	6.44
TSS (total suspended solids)	29–165[bc]		24	43	33.5	3.10	2.80	2.70	1.60	1.90	0.80	30	70	52
NH_4^+ (ammonium ion)	0–11.3[d]	0.1	1.96	3.12	4.48	1.79	2.29	BDL	2.976	3.233	3.391	6.78	4.35	4.67
NO_3^- (nitrate)	0.4–17[bc]	0.1	BDL	BDL	0.03	BDL	BDL	9.55	BDL	BDL	BDL	BDL	0.12	BDL
NO_2^- (nitrite)	<0.01–0.08[bd]	0.2	BDL	BDL	0.02	BDL	BDL	BDL	BDL	0.028	BDL	BDL	0.02	0.024
N (total nitrogen)	8.7–21[bc]		0.52	0.93	8.15	7.69	7.54	11.69	8.671	7.295	10.956	10.400	8.740	8.980
P (total phosphorus)	0.1–57[ab]		0.015	0.009	0.056	0.026	0.024	0.162	0.021	0.041	0.620	0.098	0.043	0.023
Na (sodium)	4.9–480[b]	0.001	20.015	18.495	20.609	18.530	17.817	27.566	14.347	11.57	12.051	21	17	18
Ca (calcium)	3.5–58[bc]	0.003	7.221	3.065	3.262	2.991	3.091	2.860	3.212	2.897	3.119	2.448	3.143	4.470
Mg (magnesium)	1.4–29[bc]	0.0004	1.047	0.998	1.044	0.858	0.927	1.097	0.950	0.951	0.919	0.995	0.957	0.956
SAR	4.8–6[e]		2.38	2.85	3.1	2.99	2.80	4.21	2.22	1.83	1.89	3.45	2.56	2.46
Cu (copper)	<0.05–0.3[b]	0.0006	0.053	0.44	0.074	0.069	0.066	0.094	0.082	0.035	0.066	0.044	0.023	0.063
Zn (zinc)	<0.2–6.3[b]	0.00015	0.175	0.167	0.184	0.055	0.066	0.220	0.139	0.078	0.043	0.061	0.023	0.169
Al (aluminium)	<1–21[b]	0.0021	0.044	0.05	BDL	0.008	0.018	0.046	BDL	0.016	0.056	0.037	0.039	0.113
B (boron)	<0.1–0.5[b]	0.0006	0.46	0.072	0.059	0.021	0.019	0.068	0.037	0.034	0.018			
Cd (cadmium)	<0.06–2.5[f]	0.0003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.001	BDL	BDL
Fe (iron)	<0.34–1.1[b]	0.0007	0.048	0.097	0.109	0.012	0.035	0.099	0.086	BDL	BDL	0.093	0.091	0.132
K (potassium)	1.1–59[b]	0.007	7.777	5.99	8.583	6.202	6.162	12.247	9.855	8.625	9.308	14.076	9.147	8.446
Mn (manganese)	<0.03[b]	0.00008	0.009	0.005	0.005	0.002	0.003	0.005	BDL	0.003	0.0032	0.005	0.004	0.007
Ni (nickel)	<1.3–28[f]	0.001	BDL	BDL	BDL	0.005	0.004	0.009	BDL	BDL	BDL	0.004	0.007	0.006
Pb (lead)	<0.03–6.9[f]	0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.004	0.007	0.005
S (sulphur)	<1.2–72[c]	0.007	5.491	4.4	5.489	4.696	4.240	4.097	4.144	2.964	3.809	2.547	2.859	5.043
NOTES														
Activities														

[a] (Birks & Hill, 2007). [b] (Eriksson, Affarth, Henze, & Ledin, 2002). [c] (Gross, Maimon, Alfiya, & Friedler, 2008). [d] (Paulo, Boncz, Asmus, Jonsson, & Ide, 2007). [e] (Mohammed, Kassim, Anda, & Dallas, 2013). [f] (Surendran & Wheatley, 1998). ^ Detection limit. BDL: below detection limit. $^+$ 3-monthly samples.

B1 (POST-TREATMENT)	Guide*	Limit^	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
MICROBIOLOGY														
E. coli (MPN/100mL)	0–10^7	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Salmonella spp. (MPN/100mL)	0–10^4	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Campylobacter spp. (MPN/100mL)	0	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Giardia (cysts/10L)+	0	1			BDL			BDL			BDL			BDL
Cryptosporidium spp. (ooscyts/10L)+	0	1			BDL			BDL			BDL			BDL
Culturable *adenovirus* (IU/L)+		1			BDL			BDL			BLD			BDL
CHEMISTRY														
pH	5–10[ab]		6.43	6.74	6.55	6.483	6.65	6.90	5.53	6.64	6.94	6.99	6.76	5.78
TSS (total suspended solids)	29–165[bc]		3	146	33	15	1.5	3	1.5	9.5	-	10.5	-	-
NH_4^+ (ammonium ion)	0–11.3[d]	0.1	0.15	0.18	0.13	BDL	0.28	0.46	BDL	BDL	BDL	BDL	BDL	BDL
NO_3^- (nitrate)	0.4–17[bc]	0.1	0.45	0.41	0.43	0.43	0.42	BDL	BDL	0.409	0.374	0.29	0.47	0.12
NO_2^- (nitrite)	<0.01–0.08[bd]	0.2	BDL	BDL	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
N (total nitrogen)	8.7–21[bc]		2.84	0.48	1.09	0.41	0.89	0.98	0.506	7.952	1.132	BDL	BDL	BDL
P (total phosphorus)	0.1–57[ab]		0.003	0.01	BDL	0.002	0.002	0.004	0.007	0.005	0.006	0.013	0.005	0.009
Na (sodium)	4.9–480[b]	0.001	9.347	9.257	11.226	11.423	8.982	10.240	8.060	6.289	7	8	8	3
Ca (calcium)	3.5–58[bc]	0.003	2.459	2.475	2.607	2.419	1.873	1.785	0.904	1.723	1.725	1.441	1.470	0.488
Mg (magnesium)	1.4–29[bc]	0.0004	0.812	0.823	0.895	0.805	0.683	0.711	1.064	0.661	0.737	0.694	0.677	0.405
SAR	4.8–6[e]		1.6	1.58	1.85	1.97	1.72	1.96	1.49	1.24	1.32	1.65	1.71	1
Cu (copper)	<0.05–0.3[b]	0.0006	0.217	0.264	0.174	0.100	0.052	0.077	0.022	0.207	0.034	0.094	0.023	0.060
Zn (zinc)	<0.2–6.3[b]	0.00015	0.072	0.102	0.071	0.067	0.038	0.152	0.403	0.294	0.010	0.090	0.010	0.129
Al (aluminium)	<1–21[b]	0.0021	0.007	0.005	BDL	BDL	0.004	0.005	0.004	BDL	BDL	BDL	0.002	BDL
B (boron)	<0.1–0.5[b]	0.0006	0.049	0.057	0.038	0.019	0.010	0.020	0.013	0.012	0.008			
Cd (cadmium)	<0.06–2.5[f]	0.0003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Fe (iron)	<0.34–1.1[b]	0.0007	0.004	0.003	BDL	BDL	0.005	0.004	BDL	BDL	BDL	BDL	BDL	0.021
K (potassium)	1.1–59[b]	0.007	2.049	1.838	3.282	2.449	2.044	2.256	0.710	2.452	2.938	2.755	3.131	0.432
Mn (manganese)	<0.03[b]	0.00008	0.004	0.001	0.003	0.002	0.001	BDL	BDL	BDL	0.0001	0.001	0.001	0.008
Ni (nickel)	<1.3–28[f]	0.001	BDL	BDL	BDL	0.003	BDL	0.042	BDL	BDL	BDL	BDL	BDL	BDL
Pb (lead)	<0.03–6.9[f]	0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.005	BDL	0.008
S (sulphur)	<1.2–72[c]	0.007	1.117	0.834	1.251	1.327	1.174	0.979	1.003	0.670	0.712	0.532	0.833	0.424
NOTES														
Activities														

[a] (Birks & Hill, 2007). [b] (Eriksson, Affarth, Henze, & Ledin, 2002). [c] (Gross, Maimon, Alfiya, & Friedler, 2008). [d] (Paulo, Boncz, Asmus, Jonsson, & Ide, 2007). [e] (Mohammed, Kassim, Anda, & Dallas, 2013). [f] (Surendran & Wheatley, 1998). ^ Detection limit. BDL: below detection limit. + 3-monthly samples.

C1 (PRE-TREATMENT)	Guide*	Limit^	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
MICROBIOLOGY (MPN/100mL)														
E. coli (MPN/100mL)	1	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
Salmonella spp. (MPN/100mL)		2	BDL	BDL	BDL	4	BDL	BDL	BDL	BDL	BDL	-		
Campylobacter spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
CHEMISTRY														
pH	7–8		4.96	5.02	5.69	6.18	5.49	6.70	5.86	6.32	6.08		Rainwater system closed for relocation due to adjacent construction	
TSS (total suspended solids)			456	9.5	-	0.2	1.5	0.5	0.3	1.2	-			
NH_4^+ (ammonium ion)	1.5	0.1	0.21	0.12	BDL	0.04	0.11	0.41	BDL	BDL	0.20			
NO_3^- (nitrate)	50	0.1	0.51	0.52	0.29	0.13	0.24	0.04	0.16	0.33	0.24			
NO_2^- (nitrite)	3	0.2	BDL	BDL	BDL				BDL	BDL	BDL			
N (total nitrogen)			0.82	0.48	0.67	-	-	0.43	0.81	0.33	0.26			
P (total phosphorus)			0.011	0.003	BDL	BDL	0.002	0.005	BDL	BDL	BDL			
Na (sodium)	200	0.001	3.505	3.506	1.917	1.879	3.863	0.379	1.567	1.988	1.167			
Ca (calcium)		0.003	1.746	1.716	BDL	0.677	2.595	3.276	1.654	2.454	BDL			
Mg (magnesium)		0.0004	0.430	0.416	0.148	0.138	0.486	0.379	0.229	0.275	0.152			
SAR			0.767	0.776	1.068	0.115	0.166	0.134	1.710	0.330	1.070			
Cu (copper)	2	0.0006	0.019	0.019	0.011	0.010	0.012	0.014	0.006	0.020	0.004			
Zn (zinc)	1.5	0.00015	0.121	0.186	0.072	0.032	0.072	0.080	0.060	0.069	0.031			
Al (aluminium)	0.1	0.0021	0.038	0.035	BDL	0.009	0.026	0.024	0.011	0.009	0.008			
B (boron)	1.4–2.4	0.0006	0.033	0.076	0.040	0.010	0.024	0.027	0.008	0.024	0.011			
Cd (cadmium)	0.003–0.004	0.0003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
Fe (iron)	0.2	0.0007	0.005	0.007	0.014	0.003	0.064	0.097	0.007	BDL	BDL			
K (potassium)		0.007	0.284	0.387	0.430	0.194	0.743	0.450	0.317	0.499	0.348			
Mn (manganese)	0.4	0.00008	0.034	0.025	0.010	0.006	0.050	0.330	0.009	0.011	0.005			
Ni (nickel)	0.07–0.08	0.001	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
Pb (lead)	0.01	0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
S (sulphur)	250	0.0072	1.311	1.180	0.529	0.489	1.470	1.477	1.053	1.188	0.601			
NOTES														
Activities									< - Adjacent construction site - >					

* (Ministry of Health, 2008). ^ Detection limit. BDL: below detection limit.

C3 (PRE-TREATMENT)	Guide*	Limit^	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
MICROBIOLOGY (MPN/100mL)														
E. coli (MPN/100mL)	1	1	6.7×10^{1}	3.1×10^{3}	1.2×10^{2}	49	$>2.4 \times 10^{3}$	8.5×10^{2}	220	2	23	22	>2400	61
Salmonella spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Campylobacter spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
CHEMISTRY														
pH	7–8		6.35	6.66	6.27	6.58	6.67	6.78	6.43	7.01	7.36	7.30	7.13	7.41
TSS (total suspended solids)			-	9	2.5	1.2	1.9	-	-	1.1	0.3	2.00	0.00	0.00
NH_4^+ (ammonium ion)	1.5	0.1	0.22	0.18	0.15	0.40	0.04	1.49	BDL	BDL	BDL	0.05	0.05	BDL
NO_3^- (nitrate)	50	0.1	1.23	1.06	0.96	1.04	0.08	0.03	0.702	0.221	0.451	0.39	0.26	0.33
NO_2^- (nitrite)	3	0.2	BDL	BDL	BDL				BDL	BDL	BDL	BDL	BDL	BDL
N (total nitrogen)			0.28	0.81	1.53	1.39	-	1.54	BDL	0.872	12.862	BDL	BDL	BDL
P (total phosphorus)			0.049	0.034	0.050	0.100	0.015	0.141	0.057	0.026	0.013	0.022	0.017	0.012
Na (sodium)	200	0.001	8.263	10.705	5.028	7.360	11.770	12.784	4.198	6.281	6.603	12.630	7.492	7.140
Ca (calcium)		0.003	4.705	5.074	2.961	3.065	10.383	9.175	4.174	8.629	12.574	10.018	9.484	10.160
Mg (magnesium)		0.0004	1.229	0.884	0.705	0.847	2.039	1.965	0.772	1.600	1.970	2.295	1.723	1.794
SAR			1.086	1.743	0.851	1.183	1.107	1.257	0.330	1.070	0.850			
Cu (copper)	2	0.0006	0.034	0.037	0.052	0.039	0.015	0.036	0.019	0.018	0.007	0.012	0.006	0.004
Zn (zinc)	1.5	0.00015	0.593	0.459	0.521	0.336	0.153	0.155	0.244	0.153	0.057	0.056	0.033	0.022
Al (aluminium)	0.1	0.0021	0.012	0.007	BDL	0.004	0.004	0.008	BDL	BDL	0.004	0.006	0.018	0.010
B (boron)	1.4–2.4	0.0006	0.049	0.085	0.090	0.033	0.035	0.040	0.014	0.030	0.027			
Cd (cadmium)	0.003–0.004	0.0003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.0011	0.0004
Fe (iron)	0.2	0.0007	0.016	0.008	0.017	0.001	0.003	0.007	0.002	BDL	BDL	BDL	0.0008	BDL
K (potassium)		0.007	0.942	1.462	1.121	1.253	1.734	2.035	1.077	1.189	1.271	1.597	1.242	1.144
Mn (manganese)	0.4	0.00008	0.029	0.059	0.047	0.054	0.036	0.005	0.005	0.004	0.002	0.002	0.002	0.002
Ni (nickel)	0.07–0.08	0.001	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb (lead)	0.01	0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.007	0.007	0.007
S (sulphur)	250	0.0072	2.670	3.933	1.420	1.712	2.271	2.638	1.209	1.614	1.644	1.818	1.179	1.112
NOTES														
Activities														

* (Ministry of Health, 2008). ^ Detection limit. BDL: below detection limit.

W1 (PRE-TREATMENT)	Guide*	Limit^	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
MICROBIOLOGY (MPN/100mL)														
E. coli (MPN/100mL)	1	1	BDL	BDL	BDL	BDL	BDL	BDL	4	BDL	2	BDL	3	BDL
Salmonella spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Campylobacter spp. (MPN/100mL)		2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
CHEMISTRY														
pH	7–8		5.57	5.75	5.84	6.27	6.47	5.92	6.06	6.41	3.16	5.94	5.61	6.28
TSS (total suspended solids)			2.00	-	9.00	-	-	-	-	0.100	-	1.50	3.50	1.00
NH_4^+ (ammonium ion)	1.5	0.1	0.13	0.16	0.29	0.08	-	0.09	BDL	BDL	BDL	0.04	0.03	BDL
NO_3^- (nitrate)	50	0.1	0.15	0.15	BDL	0.30	0.15	0.04	BDL	0.297	BDL	BDL	0.17	0.11
NO_2^- (nitrite)	3	0.2	BDL	BDL	BDL				BDL	BDL	BDL	BDL	BDL	BDL
N (total nitrogen)			0.31	0.31	0.65	-	-	-	0.297	0.531	0.306	BDL	BDL	BDL
P (total phosphorus)			0.006	BDL	0.070	0.004	0.002	0.011	BDL	BDL	BDL	0.005	0.005	0.005
Na (sodium)	200	0.001	13.394	10.422	8.322	24.549	15.776	12.880	11.805	6.796	6.038	38.984	5.188	5.465
Ca (calcium)		0.003	1.498	1.528	1.959	3.517	2.367	1.268	1.237	1.019	BDL	2.699	0.681	0.788
Mg (magnesium)		0.0004	1.742	1.251	1.331	2.906	1.870	1.518	1.603	1.133	0.816	4.807	0.630	0.708
SAR			1.937	1.706	1.285	2.639	2.101	2.467	1.070	0.850	1.290			
Cu (copper)	2	0.0006	0.010	0.011	0.086	0.037	0.016	0.008	0.007	0.053	0.002	0.007	0.003	0.007
Zn (zinc)	1.5	0.00015	0.167	0.150	4.145	2.339	3.388	0.147	0.077	3.170	0.013	0.101	0.053	1.703
Al (aluminium)	0.1	0.0021	0.019	0.015	0.025	0.006	BDL	0.007	BDL	BDL	BDL	0.005	0.005	0.002
B (boron)	1.4–2.4	0.0006	0.041	0.057	0.050	0.028	0.026	0.023	0.001	0.016	0.006			
Cd (cadmium)	0.003-0.004	0.0003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.0004	0.0004
Fe (iron)	0.2	0.0007	0.006	0.013	7.226	0.017	0.019	0.007	BDL	BDL	BDL	0.005	BDL	0.010
K (potassium)		0.007	0.633	0.458	0.668	1.163	0.682	0.642	0.731	0.468	0.389	2.010	0.356	0.356
Mn (manganese)	0.4	0.00008	0.009	0.009	0.046	0.040	0.032	0.004	BDL	0.016	BDL	0.010	0.004	0.020
Ni (nickel)	0.07–0.08	0.001	BDL	BDL	0.368	0.159	0.298	BDL	0.007	0.117	BDL	BDL	0.003	0.115
Pb (lead)	0.01	0.003	BDL	BDL	0.145	BDL	BDL	BDL	BDL	BDL	BDL	0.005	0.004	BDL
S (sulphur)	250	0.007	1.548	1.119	1.460	2.560	1.722	1.265	1.114	0.731	0.581	3.163	0.478	0.417
NOTES														
Activities					< - Adjacent construction site - >									

* (Ministry of Health, 2008). ^ Detection limit. BDL: below detection limit.