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A comparison of the microbiological quality of drinking-water of urban and semi-urban dwellings in the Richmond district of New Zealand

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Abstract

This study aimed to determine if residents of Richmond, Nelson, with an on-demand, mains pressure, and metered drinking-water supply had the same microbiological drinking-water quality at the kitchen tap as dwellings with a restricted, low-flow supply. Both dwelling types were supplied with water from the same untreated, reticulated water supply scheme. The results from this study provide information for both consumers and the supplier regarding the microbiological quality of drinking-water supplied at the kitchen tap.

A cross-sectional, interviewer administered survey of 50 dwellings with a metered supply and 61 dwellings with a restrictor supply was conducted during May-July 2012. Microbiological water quality of each dwelling was ascertained by testing water samples from the kitchen tap for the presence of indicator organisms, using the Colilert®-18 method.

When total coliforms were used as an indicator, metered dwellings did not have the same water quality as restrictor-only dwellings ($p<0.0005$): more restrictor-only dwellings were contaminated than metered dwellings. Drinking-water at the kitchen tap for 84% of metered dwellings and 48% of restrictor-only dwellings complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 total coliform per 100 ml. When *E.coli* was used as an indicator, metered dwellings were found to have the same water quality as restrictor-only dwellings ($p=0.242$). Drinking-water for all metered dwellings and 94% of restrictor-only dwellings complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 *E.coli* per 100 ml. Supplementing the reticulated water supply with water from another source was undertaken by 18% of participants with a restrictor supply and it appeared to cause a reduction in the microbiological quality of drinking-water.

The results for *E.coli* have demonstrated that it is possible to provide a potable supply of drinking-water from an untreated, reticulated supply to dwellings with either a metered or a restrictor-only supply. The total coliform results indicated that there might be issues with the use of restrictor drinking-water supplies, in particular the use of private water storage systems. Owners of restrictor supplies need to be provided with more information on the set-up, design, and maintenance of these water storage systems.

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1 Introduction

Reticulated drinking-water supplies; also known as piped, or network mains water supplies, are essential for providing millions of people worldwide with an adequate, potable, and easily available supply of water. Reticulated supplies are vital not only for the health of communities but also for supporting business and industries (Gray, 2008). In 2010-2011, over three million people in New Zealand were provided with drinking-water from a registered, reticulated drinking-water supply (Ministry of Health [MoH], 2012a).

In New Zealand, as in other countries such as the United Kingdom (Gray, 2008) and Germany (Völker, Schreiber, & Kistemann, 2010), drinking-water suppliers that supply reticulated drinking-water to households are legally responsible for the quality of the water whilst it is in the public network. Water is deemed to be in the public network until it reaches the stopcock, restrictor, or the meter of a property. After this point, property owners are responsible for drinking-water quality (Building Act, 2004; Gray, 2008; Health Act, 1956; Völker et al., 2010).

Large reticulated drinking-water suppliers in New Zealand (those serving more than 10,000 people per year) are legally obliged to demonstrate that drinking-water distributed in the public network is potable (Health (Drinking Water) Amendment Act, 2007; MoH, 2012b). However, testing to demonstrate that water is potable is undertaken in the distribution network, before the meter or restrictor valve, not at the consumer's tap (MoH, 2008). Research undertaken overseas has shown not only that water quality can change within the distribution network (Payment, Franco, & Siemiatycki, 1993), but changes in water quality can also occur in household pipes (Lautenschlager, Boon, Wang, Egli, & Hammes, 2010; Pepper et al., 2004). Furthermore, in regional New South Wales, Australia, where distribution zone sampling occurs at the consumer's tap, almost 40% (129/323) of the regional water supply systems were found to have *Escherichia coli* (*E.coli*) present in more than two out of every 100 samples taken for microbiological analysis (Cretikos et al., 2010).

Households in New Zealand, supplied via a reticulated supply, can either be provided with water directly from the network, usually via a water meter, or they are supplied with water via a restrictor. Households with a restrictor are supplied with a low-flow, low-pressure supply that trickle feeds into one or more private water storage tanks. To obtain a full-pressure supply at the dwelling storage tanks either have to be located higher than the dwelling, or a water pump has to be used (MoH, 2010c). Owners of these reticulated supplies are not only responsible for the quality of water but also for all fixtures and fittings; such as pipes, pumps, and storage tanks, that are located on the dwelling side of the restrictor valve (Building Act, 2004; Health Act, 1956).

Householders with non-reticulated supplies, who have to store their water prior to use, have been found to carry out minimal maintenance on their drinking-water systems (Baguma, Loiskandl, Darnhofer, Jung, & Hauser, 2010; Richardson, Nichols, Lane, Lake, & Hunter, 2009; Rodrigo, Sinclair, & Leder, 2010). Water storage tanks are seldom cleaned or inspected (Abbott, Douwes, & Caughley, 2006; Thompson, 2011a) and water testing, to determine safety of the water supply, is rarely undertaken (Hexemer et al., 2008; Jones et al., 2006; Thompson, 2011a). Research has also shown that water supplied from these non-reticulated systems is often microbiologically contaminated (Abbott et al., 2006; Hexemer et al., 2008; Kay et al., 2007; Reid, Edwards, Cooper, Wilson, & McGaw, 2003; Richardson et al., 2009; Simmons, Hope, Lewis, Whitmore & Gao, 2001).

There has, however, been no research to date to determine if drinking-water, supplied via a restrictor from a reticulated supply, is microbiologically safe to drink at the kitchen tap. The purpose of this study was to compare the microbiological quality of drinking-water of dwellings with an on-demand, metered water supply to dwellings with a restricted, low-flow supply, where both dwelling types were supplied from the Richmond urban water supply scheme. Total coliforms and *E.coli* were used as indicators of water quality and the results obtained were compared to the microbiological standards set in the Drinking-water Standards New Zealand (DWSNZ) 2005 (Revised 2008) to determine if the drinking-water supplied to these dwellings complied with these Standards.

This study was limited to one urban water supply network: the Richmond urban water scheme. At the time of this study, this scheme was a ‘large’ reticulated supply, owned by the Tasman District Council, which provided water to approximately

11,200 people (Tasman District Council [TDC], 2012d). The supply was sourced from groundwater, was untreated (TDC, 2012d), did not have plant compliance with the Drinking-water Standards New Zealand 2005 (Revised 2008) but did have distribution zone compliance (Drinking Water for New Zealand, 2012b). Water from this scheme was supplied to dwellings with either a metered or a restrictor supply (TDC, 2012d). Using the Richmond supply for this research allowed comparisons of microbiological water quality to be made between dwellings with a metered supply and dwellings with a restrictor supply, that have to store their water prior to use.

This research was significant as it was the first time that research of this type had been undertaken in New Zealand. The results of this study should provide information for consumers, suppliers, and policy makers. Consumers would know if the water at the kitchen tap was safe to drink; suppliers would know if water with distribution zone compliance was still potable when it reached the consumer, and policy makers would know if the legislation and standards implemented in New Zealand were effective in the supply of potable water. Furthermore, information would be provided about the use of private water storage systems and whether these systems were effective in the provision of potable drinking-water.

This thesis has been divided into nine sections. The thesis begins with a background section providing information about the Richmond water supply along with a literature review of the existing literature relevant to this study. The aim and objectives of the study are contained in Section 4. Methodology, justification for the methods employed, and information on sampling and data analysis are included in Section 5 and Section 6. Section 7 provides the results of the study and Section 8 provides a discussion of the results in relation to the existing body of knowledge. The final section of this thesis provides a conclusion and a reflective evaluation of this research study.

2 Background

2.1 The Tasman District

The Tasman District is located in the northern part of the South Island of New Zealand. It covers an area of 9,786 km^2 (TDC, 2005) and has a population of approximately 44,625 people (Statistics New Zealand, 2007). There are four major towns in the District: Richmond, Motueka, Takaka, and Murchison (TDC, 2005). The Tasman District Council, the Unitary Authority for the Tasman District, owns the drinking-water supply networks for these four major towns and also owns the supply networks for 12 other water supply schemes (TDC, 2012d).

2.2 Richmond urban water scheme

2.2.1 Source

The largest water supply scheme owned by the Tasman District Council is the Richmond urban water scheme. This scheme supplies drinking-water to a population of approximately 11,200 people who live in the Richmond area. Water for the Richmond supply is sourced from a confined aquifer in the Waimea Plains and a further 10 m^3/day of water is sourced from the Nelson City Council's Roding dam supply (TDC, 2012d).

There are five bores that provide water for the Richmond scheme: four in Lower Queen Street and one in Appleby (Figure 1 and Figure 2). These bores are all approximately 30 m deep with screen depths ranging from 26.5 m to 32.9 m (G. Bullock, personal communication, March 23, 2012). Water for these bores comes from the lower confined aquifer (TDC, 2012d). The bores do not have current Ministry of Health 'secure' status even though the bore water in three of the wells has been shown, using tritium, to have a mean residence time of at least 30 years (G. Bullock, personal communication, March 23, 2012; Stewart, 2011).

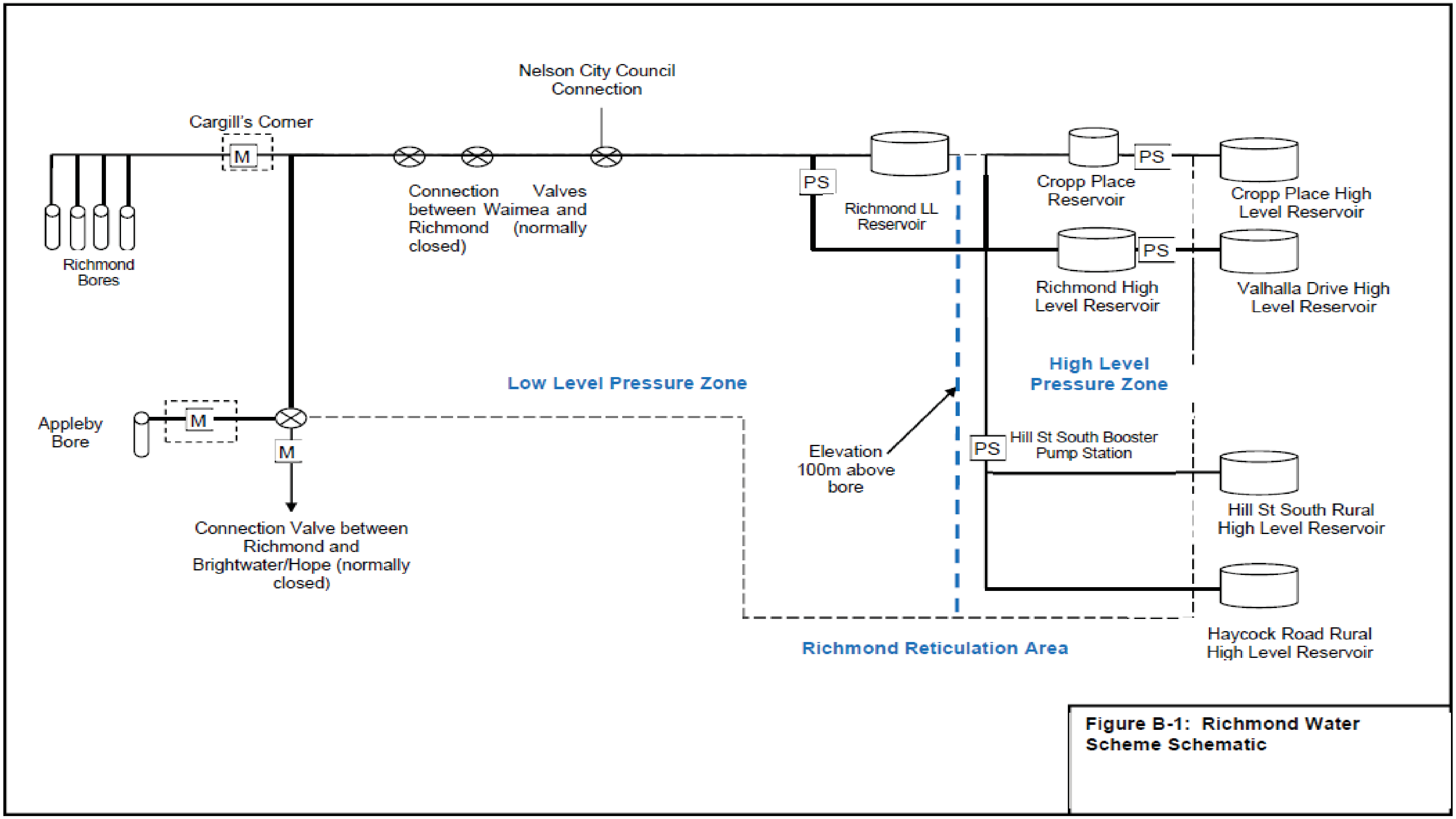

Figure 1. **Schematic of Richmond water supply (TDC, 2012d)**

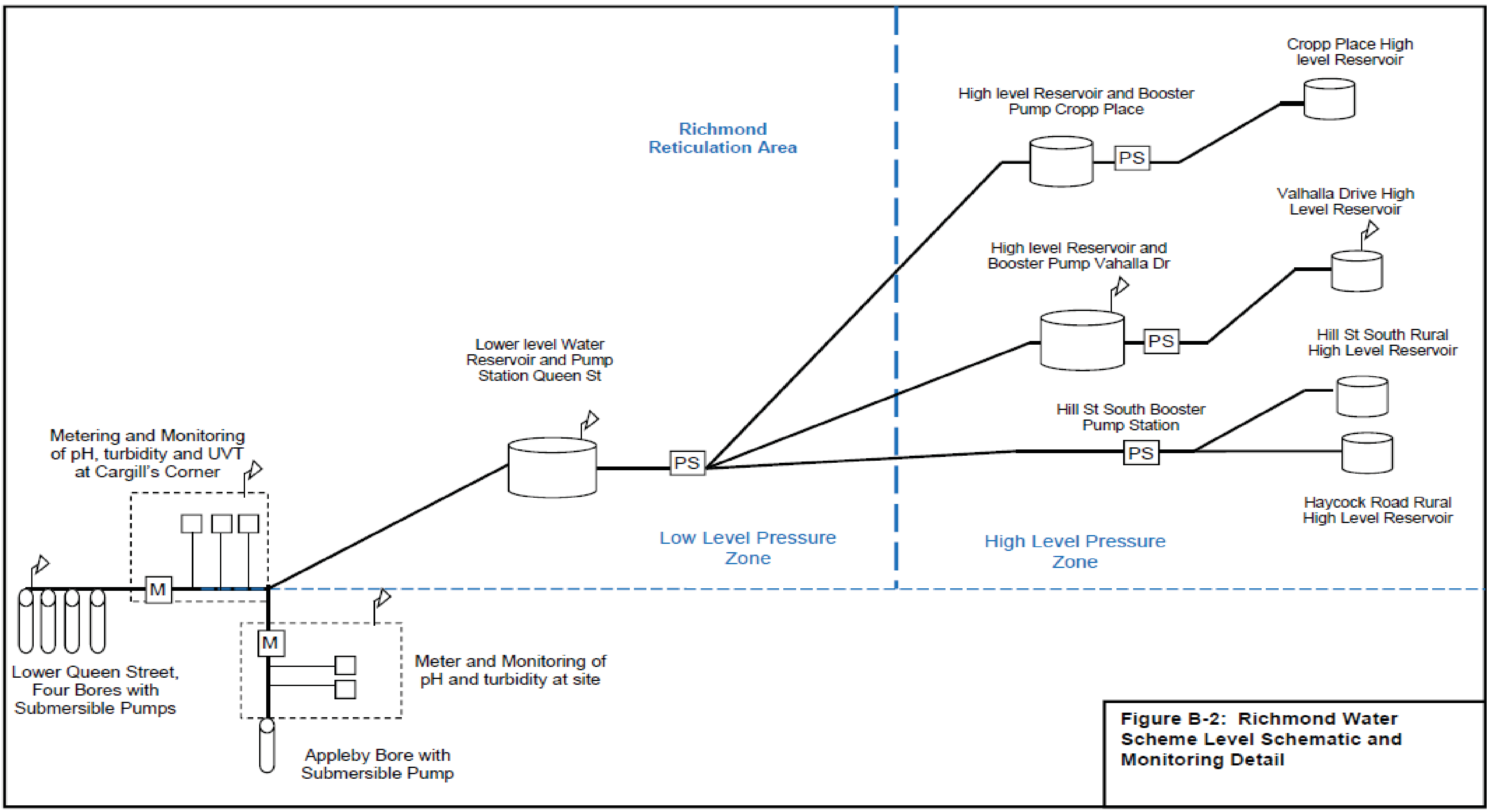

Figure 2. Richmond water scheme with monitoring detail (TDC, 2012d)

2.2.2 Distribution

Water is pumped from the five bores, without being treated, to the low level pressure supply zone and to the main storage reservoir in Queen Street, Richmond (Figure 1 and Figure 2). Water from this reservoir either gravity feeds back into Richmond, to supply dwellings in the low level pressure zone with drinking-water, or the water is pumped to a second reservoir that supplies water to the high level pressure zone. A series of booster pumps and storage reservoirs exist to ensure the supply of water to properties at the top end of the zones and to rural properties (TDC, 2012d). Reservoirs are constructed from either plastic or concrete and sizes vary, with the largest being the Queen Street reservoir at 2.25 million litres and the smallest being the Cropp Place reservoir at 4,500 litres (TDC, 2009). Pipes within the network are made of a variety of materials such as asbestos cement, polyvinylchloride (PVC), high density polyethylene (HDPE), copper, and cast iron (TDC, 2005, 2012d).

2.2.3 Maintenance

Downer NZ Ltd is under contract to MWH New Zealand Ltd to undertake operational and maintenance tasks on the Richmond water supply (TDC, 2012d). A cyclical maintenance spread sheet is utilised which provides details of the tasks that need to be undertaken and a timeframe for completing these tasks. Reservoirs are inspected twice a year and cleaned as required. Dead end mains are flushed four times a year. A mechanical check of pump stations is done once a year and electrical and telemetry checks of the pump stations are done four times a year. Water testing in the distribution zone is carried out at fixed, specified locations at least 19 times per quarter. Other tasks, such as fixing burst water pipes, are undertaken as and when required (G. Bullock, personal communication, August 10, 2012).

2.2.4 Metered and restrictor supplies

Water from the Richmond scheme is supplied to two types of dwelling: urban dwellings with an on-demand, mains pressure, metered supply and semi-urban dwellings with a restricted, low-flow supply (Figure 3). There are approximately 5,000 metered connections and 100 restrictor connections supplied with drinking-water from the Richmond urban water scheme (TDC, 2009, 2012d).

Metered dwellings are located in urban areas in both the low and high level pressure zones (Figure 1 and Figure 2). Each metered property has its own water meter and owners of these properties receive a water bill twice a year. Current water rates are based on a flat rate daily charge of 61.81 cents per day and then a usage charge of \$1.87 per m^3 of water used (TDC, 2012a).

Semi-urban dwellings, with a restrictor supply, are located on the southern and western boundaries of the Richmond supply (Figure 3). Owners of dwellings with a restrictor supply can choose to receive either 1 m^3 or 2 m^3 of water per day. This water is supplied to them via a restrictor valve at their property boundary. Water trickles in through this valve at a set rate of approximately 0.69 L/min for 1 m^3 per day or double this rate for 2 m^3 per day (G. Bullock, personal communication, August 10, 2012). As the trickle supply is a low pressure supply, owners of these dwellings have to store their water prior to use. The Council charges an annual rate of \$344.15 per annum for supplying 1 m^3 of water per day to a dwelling with a restrictor supply. Next rating year (2012/2013) the supply of 1 m^3 per day of water to a restrictor dwelling will rise to \$546.91 per annum (TDC, 2012a).

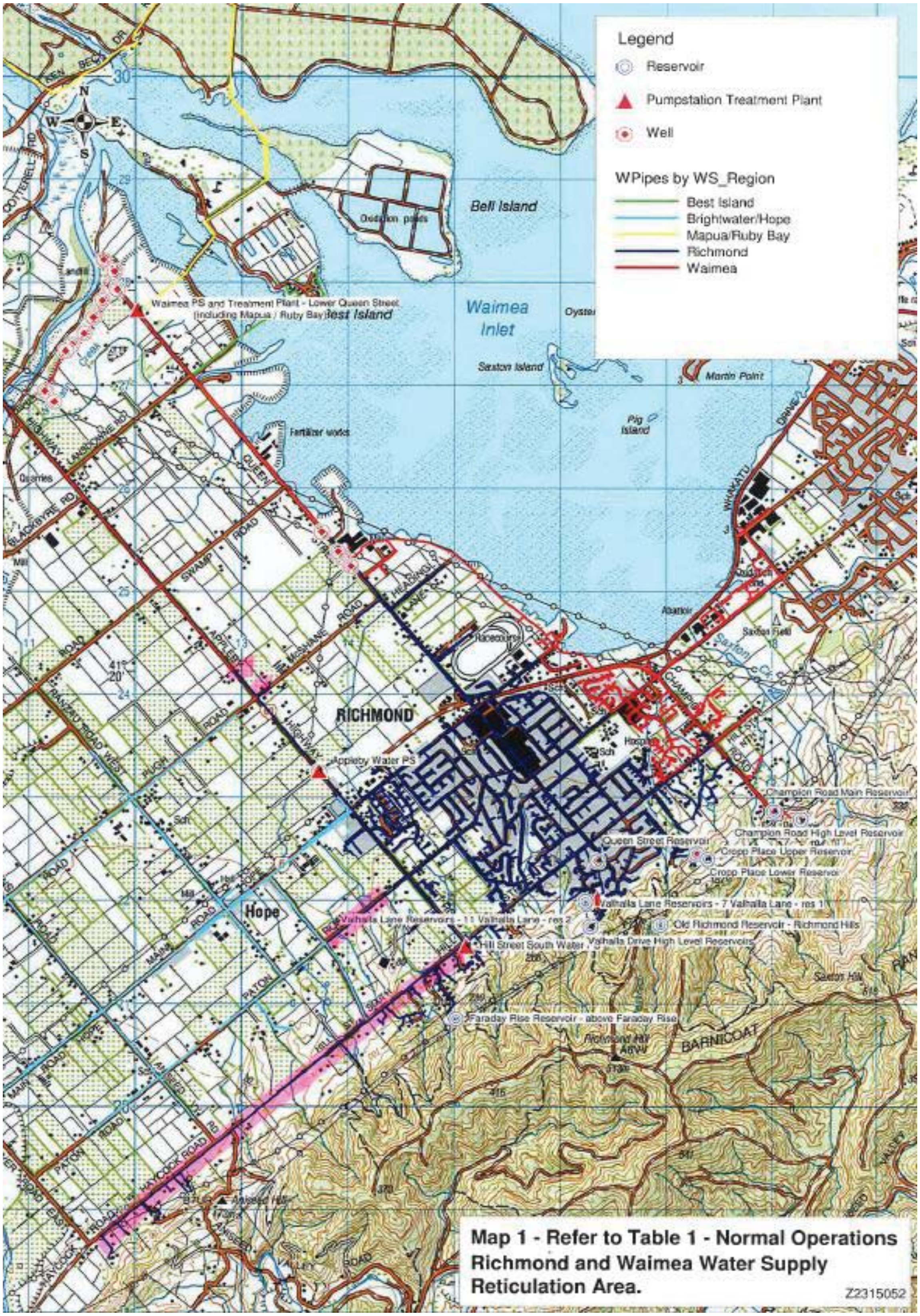

Figure 3. **Map of Richmond supply**

Areas with restrictor supplies are highlighted in pink (map supplied by G. Bullock, MWH Ltd)

2.3 Grading and compliance of the Richmond supply 2001-2011

Compliance with the DWSNZ is measured both at the plant and in the distribution zone (Section 3.2.3 and Section 3.2.5). From 2001 to 2005 the Richmond drinking-water supply had plant compliance for both *E.coli* and protozoa (Table 1). In 2006, the Drinking Water Assessor (DWA) for the Nelson Marlborough District Health Board challenged the secure groundwater status of the supply (E. Mackenzie, personal communication, April 13, 2012). Since then, the source water has been deemed to be unsecure and the plant has had neither *E.coli* nor protozoal compliance. From 2001/2002 to 2010/2011 the supply has had *E.coli* microbiological distribution zone compliance but has not had distribution zone chemical compliance due to high levels of nitrate. Nitrate levels have often been found to exceed the maximum acceptable value (MAV) stated in the DWSNZ 2005 (Revised 2008) of 50 mg/L (Evan Mackenzie, personal communication, April 13, 2012: MoH, 2008).

Since 2001, the Richmond water supply has been ungraded (Table 1 and Section 3.2.6). The supply was ungraded as insufficient *E.coli* sampling was undertaken at the plant to achieve a grading (E. Mackenzie, personal communication, September 14, 2012). The water supply was, prior to 2006, considered to be a 'secure' source. As a 'secure' source *E.coli* sampling for compliance need only be undertaken at the plant once a month. To gain compliance as a 'non-secure' source, *E.coli* sampling should be undertaken daily (MoH, 2008). The Tasman District Council has elected to continue sampling for *E.coli* once a month, even though the source is no longer classified as secure, for several reasons (G. Bullock, personal communication, September 17, 2012):

1. The water has traditionally been of good quality
2. There is a new treatment plant being installed
3. The expense of testing daily was believed to be unjustified.

Table 1. **Public health grading for the Richmond supply 2001 – 2011[a]**

Year	Plant	Grade	Zone
2001	*E.coli* and protozoa comply: accepted as secure groundwater source	u[b]	*E.coli* compliant. Nitrate non-compliant (Institute of Environmental Science and Research, 2002)
2002	*E.coli* and protozoa comply: accepted as secure groundwater source	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2003)
2003	*E.coli* and protozoa comply: accepted as secure groundwater source	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2005b)
2004	*E.coli* and protozoa comply: accepted as secure groundwater source	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2006a)
2005	*E.coli* and protozoa comply: accepted as secure groundwater source	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2006b)
2006/2007	Non-compliant for *E.*coli. No or ineffective protozoal treatment. Groundwater source no longer deemed secure	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2009a)
2007/2008	Non-compliant for *E.coli*. Protozoal non-compliance: Chemical non-compliance. PHRMP[c] not planned.	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2009b)
2008/2009	Non-compliant for *E.coli*: not enough samples taken. No or ineffective protozoal treatment. PHRMP in draft. Non-compliant for nitrate.	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2010a)

Year	Plant	Grade	Zone
2009/2010	Non-compliant for *E.coli*. No or ineffective protozoal treatment. PHRMP in draft. Non-compliant for nitrate.	u	*E.coli* compliant. Nitrate non-compliant (MoH, 2011)
2010/2011	Non-compliant for *E.coli*: not enough samples taken. 17 samples taken from Appleby bore with one presence/absence transgression for *E.coli*; 21 samples taken from Queen Street bores with no transgressions. Non-compliant for protozoa: not a secure source. Cyanotoxin not considered a risk. PHRMP in place.	u	*E.coli* compliant: 76 samples were required and 151 samples were taken. There were no transgressions Nitrate non-compliant: taken 24 samples and 19 were above the MAV. Protozoa non-compliant. Cyanotoxin not considered a risk (MoH, 2012a)

[a]Information for this table was also supplied by Evan Mackenzie, personal communication, April 13, 2012
[b]u=ungraded
[c]Public Health Risk Management Plan

2.4 Current compliance status and grading of the Richmond supply

2.4.1 Compliance with the Health Act 1956

At the time of writing the Richmond supply is registered on the Register of Community Drinking-water Supplies in New Zealand (Drinking Water for New Zealand, 2012a, b). The supply does not meet all of the requirements of Section 69 of the Health Act 1956, as amended by the Health (Drinking Water) Amendment Act 2007, but does comply with Sections 69S, 69U, 69V, 69ZD and Section 69ZE. By complying with these sections the Tasman District Council has shown that it is providing an adequate supply of water, that it has taken reasonable steps to protect the source water, and that is has taken all practicable steps to comply with the DWSNZ 2005 (Revised 2008). A public health risk management plan (PHRMP) has been prepared and approved and the

Council has met the record keeping and complaints procedure requirements contained in the Act (MoH, 2012a).

2.4.2 Bacterial compliance with the DWSNZ 2005 (Revised 2008) for water leaving the treatment plant

When this survey was undertaken the Richmond town supply did not have bacterial compliance for water leaving the treatment plant (Drinking Water for New Zealand, 2012b; E. Mackenzie, personal communication, April 13, 2012). The bores were not certified as secure and the Council was not undertaking daily *E.coli* testing. To gain compliance for water leaving the treatment plant the Tasman District Council would either have had to undertake daily *E.coli* testing or had the bores certified as secure (MoH, 2008).

In December 2011, a major transgression occurred when a count of 23 *E.coli* per 100 ml was found in a sample taken from one of the Queen Street bores (J. Cuthbertson, personal communication, March 16, 2012). The DWA was informed. Sampling on subsequent days showed that *E.coli* was still present in the supply with counts of one *E.coli* per 100 ml. A boil water notice had to be issued for all dwellings supplied with drinking-water from the Richmond urban water scheme (Murdoch, 2012). The *E.coli* was believed to have entered the well at the bore headworks. An extreme rainfall event had occurred prior to sampling (TDC, 2012b) and the bore headworks had become submerged. When the pumps turned on a small amount of water was sucked into the well through a gasket seal at the headworks, which was not sealing properly (G. Bullock, personal communication, January 7, 2013).

A further contamination event occurred whilst this study was being carried out. Routine testing of well water revealed that there was a contamination problem with well No. 3. The cause of the contamination could not be determined and the well was shut down on May 18th 2012. Due to the nature of the Richmond supply the water from this well might have remained in the distribution system for a few days after the well had been shut down (G. Bullock, personal communication, November 26, 2012).

2.4.3 Bacterial compliance with the DWSNZ 2005 (Revised 2008) for water in the distribution zone

When this survey was undertaken the Richmond supply had distribution zone *E.coli* compliance with criterion 6A of the DWSNZ 2005 (Revised 2008) (Drinking Water for New Zealand, 2012b). To gain this compliance, *E.coli* water testing had to be carried out at least 19 times per quarter, from regular sampling points in the distribution network. If a positive *E.coli* test result had occurred, remedial action would have to be undertaken, as specified in the DWSNZ 2005 (Revised 2008). This remedial action would include informing the DWA of the transgression, along with daily sampling, and an investigation into the possible cause of the contamination. The DWA would need to be informed immediately and instant remedial actions would have to be undertaken if the results of any sample were ≥10 *E.coli* per 100 ml (MoH, 2008).

2.4.4 Protozoal compliance with the DWSNZ 2005 (Revised 2008)

The Richmond supply did not have protozoal compliance at the time when this survey was undertaken as the water supply was neither deemed to be from a secure source, nor was it treated. To gain protozoal compliance either the bores would have to be classified as secure, or the protozoal log credit requirement for the Richmond water supply would have to be determined. The log credit requirement of a particular treatment method has been based on international studies and it reflects the ability of a treatment process to remove or inactivate protozoa (MoH, 2008).

To gain a protozoal log credit requirement for the Richmond supply the Tasman District Council would have to follow the procedures stated in Section 5.2 of the DWSNZ 2005 (Revised 2008). The Council would need to either undertake a catchment risk category approach or undertake raw water *Cryptosporidium* monitoring (MoH, 2008). A catchment risk category approach involves undertaking a desk-top study of the water catchment area in order to provide an indication of the perceived risk from *Cryptosporidium*. Raw water *Cryptosporidium* monitoring involves taking at least 26 raw water samples, at equal time intervals, over the period of a year. The samples would have to be quantified for *Giardia* and *Cryptosporidium* oocysts. The mean number of *Cryptosporidium* oocysts present would then determine the log credit removal requirement of the treatment system (MoH, 2008). Once the log credit removal requirement had been determined then sufficient treatment mechanisms would have to be installed to meet these requirements.

To demonstrate that the bore water is secure the Tasman District Council would have to meet the following criteria set out in Section 4.5 of the DWSNZ 2005 (Revised 2008):

1. The Council would have to demonstrate that the bore water was not directly affected by surface or climatic influences. This can be done by 'aging' the water, by testing the water to show that it has constant composition, or by using a verified model that demonstrates that the water comes from a confined aquifer.
2. The Council would have to demonstrate that the bore head was secure.
3. Lastly, *E.coli* monitoring would have to be undertaken daily for the first three months and if samples showed no contamination, sampling could then be reduced and carried out monthly (MoH, 2008).

The Tasman District Council has elected to not gain protozoal compliance for the Richmond supply as they have plans to install a new treatment plant by 2015 (TDC, 2012d). When the new plant is installed the Richmond water supply will be mixed with water from the Waimea water supply scheme. As the Waimea water supply has a log 3 credit removal requirement there is no point in getting the Richmond water supply classified as a secure groundwater source (a log zero credit removal). So long as the bore heads are secure on the Richmond supply, the desk-top risk category approach automatically gives the supply a log 3 credit removal (G. Bullock, personal communication, January 7, 2013).

2.4.5 Chemical compliance with the DWSNZ 2005 (Revised 2008)

The Richmond water supply did not have current chemical compliance when this survey was undertaken, as it had a Priority 2 (P2) nitrate determinand (TDC, 2012d). There were 24 water samples taken in 2010-2011 to test for nitrate and 19 of these samples exceeded the MAV for nitrate of 50 mg/L. High nitrate levels will no longer be an issue when the new treatment plant is installed, as the Richmond source water will be diluted with water from the Waimea scheme (E. Mackenzie, personal communication, April 13, 2012).

2.4.6 Grading of the Richmond supply

The Richmond supply was, at the time this survey was conducted, an ungraded drinking-water supply (Drinking Water for New Zealand, 2012b). This was because there had been insufficient sampling to obtain a grading (E. Mackenzie, personal communication, April 13, 2012; J. Cuthbertson, personal communication, March 16, 2012).

2.5 Future plans for the Richmond water supply

The Tasman District Council has plans to upgrade the Richmond water supply scheme by 2015 (TDC, 2009, 2012a). In the long term, a further water source is being investigated to ensure an adequate supply of water in the summer months. This water source will be further inland, away from the sea, to reduce the risks of salt water intrusion (G. Bullock, personal communication, June 15, 2012). A new treatment plant is also going to be developed by 2015 (TDC, 2012d). The Tasman District Council is aiming for a Bb grading based on the DWSNZ 2005 (Revised 2008) (Controller and Auditor-General, 2010) and the cost of this upgrade is estimated to be in the region of $9 million (TDC, 2012a, 2012d).

Treatment at the new plant will include mixing and ultraviolet (UV) disinfection with possible pH correction: chlorination will not be used. Water for this treatment plant will be sourced from two different supplies: the Richmond supply scheme and the Waimea scheme. Blending of these two sources will reduce the nitrate levels in the Richmond water supply. The protozoal log credit requirement of the Waimea water scheme has already been assessed to be 3 log credits. The protozoal log credit requirement for the Richmond supply will also be 3 log credits, once the bore heads are secure (G. Bullock, personal communication, September 17, 2012). The installation of a UV treatment system will meet these log removal requirements and the Richmond urban water scheme will then comply with all microbiological criteria in the DWSNZ 2005 (Revised 2008) (G. Bullock, personal communication, March 26, 2012; TDC, 2009, 2012a).

3 Literature Review

3.1 Reticulated drinking-water supplies

Water transport systems have been used for thousands of years (May, 2002) and provide millions of people worldwide with a safe, adequate, and reliable supply of water. Reticulated water supplies deliver drinking-water from the source to the consumer via a network of pipes, pumps, and storage tanks (Shammas & Wang, 2011; Trifunović, 2006). They are usually composed of a source, a treatment plant, and a distribution network. These supplies form the backbone of communities and are essential for the continued existence of most businesses and industries**.** Reticulated supplies are also responsible for major reductions in waterborne illnesses and the advent of high-quality water supplies have been amongst the most major advances in improving human health (Ainsworth, 2004; Dawson & Sartory, 2000; Neumann, Smith, & Belosevic, 2005).

3.1.1 Source water

Water for reticulated supplies can be sourced from surface water, such as rivers and lakes; from groundwater, such as wells and aquifers; or from roof-collected rainwater (MoH, 2005c; Shammas & Wang, 2011). Groundwater is believed to be of better quality than surface water and roof-collected rainwater and can often be the most economic option available for water suppliers (MoH, 2005c; Schmoll, Howard, Chilton, & Chorus, 2006). In countries such as Austria, Denmark, and Hungary, over 90% of drinking-water supplies are sourced from groundwater (Schmoll et al., 2006).

The natural filtration process that occurs as rainwater passes through soil and sediments acts to remove pathogenic microorganisms. This means that groundwater can often be distributed to consumers with little or no treatment (Schmoll et al., 2006). In the Netherlands, approximately 232 of the 250 water treatment facilities, serving a population of 15.5 million, are sourced from groundwater and are untreated (van der Koij, van Lieverloo, Schellart, & Hiemstra, 1999). Similarly, in Norway 55% of the community groundwater supply systems are not disinfected (Kvitsand & Fiksdal, 2010). In New Zealand, groundwater sources can be supplied to the consumer without further treatment so long as they have been classified as having a 'secure' bore water source. To be classified as secure a supplier must demonstrate that the bore water is not directly affected by any climatic or surface influences and that the bore head provides satisfactory protection (MoH, 2008).

3.1.2 Treatment

Water treatment plants not only aim to reduce or remove any contamination present in a water source but also aim to produce a water supply that can be distributed to consumers without recontamination occurring (Gray, 2008; Maier, Pepper, & Gerba, 2009). The choice of treatment system utilised is often dependent on the quality of the source water (Maier et al., 2009; MoH, 2005c; World Health Organization [WHO], 2011) but usually involves one or more of a series of physical or chemical processes. A standard treatment chain begins with coagulation, and is followed by flocculation, sedimentation, filtration, and disinfection (Figure 4).

Coagulation is the process whereby a coagulant, such as aluminium sulphate, is added to the raw water to destabilise the small colloidal particles in order to cause them to aggregate into larger particles. Flocculation follows coagulation and involves mixing the water to increase the aggregation of smaller particles to form flocs. Once flocs have formed the water can be clarified by sedimentation. In this stage the flocs, which are heavier than water, settle out of the water and can then be removed. Any remaining fine solids are then removed by filtration (MoH, 2005c; Gray, 2008).

Disinfection is usually the final process in the treatment chain and is believed to be the single most important treatment in the supply of drinking-water (National Health and Medical Research Council & Natural Resource Management Ministerial Council [NHRMC & NRMMC], 2004; WHO, 2011). Disinfectants used include any one of the following: chlorine, chloramines, chlorine dioxide, ultra-violet light or ozone (MoH, 2005c). Chlorine (or chlorination) is the most commonly used disinfectant, both in New Zealand and overseas (MoH, 2005c; NHRMC & NRMMC, 2004). Its use is widespread as it is cost effective, reliable in inactivating bacteria, and it can provide a disinfectant residual in the distribution system (MoH, 2005c; WHO, 2011).

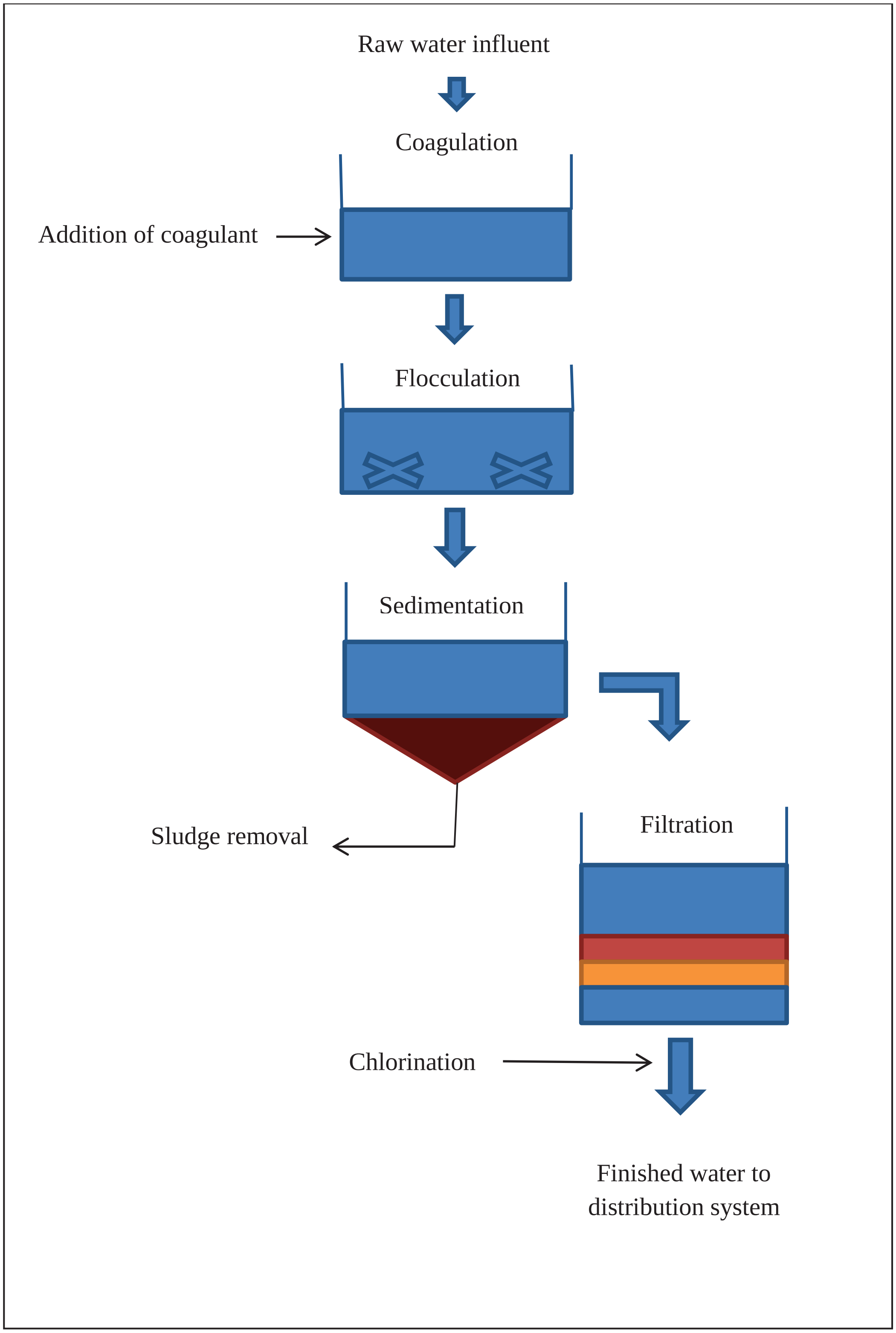

Figure 4. Diagram of a conventional treatment system

3.1.3 Distribution

The distribution system of a reticulated supply comprises the network of pipes, pumps, and water storage reservoirs that allows water to be conveyed from the treatment plant to the consumer (Gray, 2008; Trifunović, 2006). Systems must be designed to avoid dead-ends, and to prevent back-flow and cross-connections (Besner, Gauthier, Servais & Camper, 2002; Chambers, Creasey, & Forbes, 2004; Craun & Calderon, 2001). Water storage reservoirs should be covered (Kerneis, Nakache, Deguin, & Feinberg, 1995; LeChevallier, Welch, & Smith, 1996; Lee, Sang-Jong, & Seong, 2006) and be of the right size and shape to ensure that water stratification and stagnation do not occur (Chambers et al., 2004). Pumps should be sited so that water does not stagnate in tanks and pipes (Evison & Sunna, 2001; LeChevallier et al., 1996) and booster stations should be located so that a disinfection residual is maintained in the network (Levi, 2004).

Maintenance of distribution systems is also essential for ensuring a potable supply of water is delivered to the consumer (Eboigbodin, Seth, & Biggs, 2008). A maintenance and service programme should be established for each supply. Reservoirs should be examined internally and externally, and cleaned at regular intervals. Pipes should be cleaned; either by flushing, by swabbing, or by air scouring. All pumps, fittings, and valves should be serviced regularly. Other maintenance work, such as mending broken pipes, should be undertaken as and when required (Kerneis et al., 1995; MoH, 2010c; Vitanage, Pamminger, & Vourtsanis, 2004).

3.2 Framework for provision of potable water in New Zealand

3.2.1 Multiple barrier approach

To ensure reticulated water supplies are potable countries such as New Zealand, USA, Australia, and Norway have adopted the multiple barrier approach to the supply of drinking-water (Kvitsand & Fiksdal, 2010; NHRMC & NRMMC**,** 2004; Nokes, 2008a, b; Summerscales & McBean, 2011). This approach is risk management based and involves the use of more than one barrier to prevent or reduce contamination of the water supply. Emphasis is placed on preventing or reducing the entry of pathogens into a water supply rather than being reliant on end-testing to show that contamination is not present (Nokes, 2008a, b: WHO, 2011).

A 3-tier multiple barrier approach has been recommended (Figure 5). The first tier occurs at the drinking-water source and emphasises protection of the water supply source, as well as the use of the best quality source water available. The second tier involves the use of sufficient treatment mechanisms, such as filtration and disinfection, to remove any contaminants that might be present in the source water. The third tier, or set of barriers, involves the provision of an adequate distribution network so that water leaving the treatment plant can be transported to the consumer without any loss of quality. The use of more than one barrier in the supply system means that if one barrier fails there are still others in place to ensure that consumers receive a potable supply of water (Nokes, 2008a, b).

To complement this multiple barrier approach a range of public health management tools have been implemented by the Ministry of Health in New Zealand. These tools include legislation, Standards, and guidelines (Health (Drinking Water) Amendment Act, 2007; MoH, 2008; Resource Management Act, 1991; Resource Management [National Environmental Standards for Sources of Human Drinking Water] Regulations 2007). Numerous publications have also been produced to assist drinking-water suppliers in the management of drinking-water supplies (MoH, 2005a, 2005d, 2007, 2010b, d). These publications provide information on topics such as PHRMPs and supply system set-up.

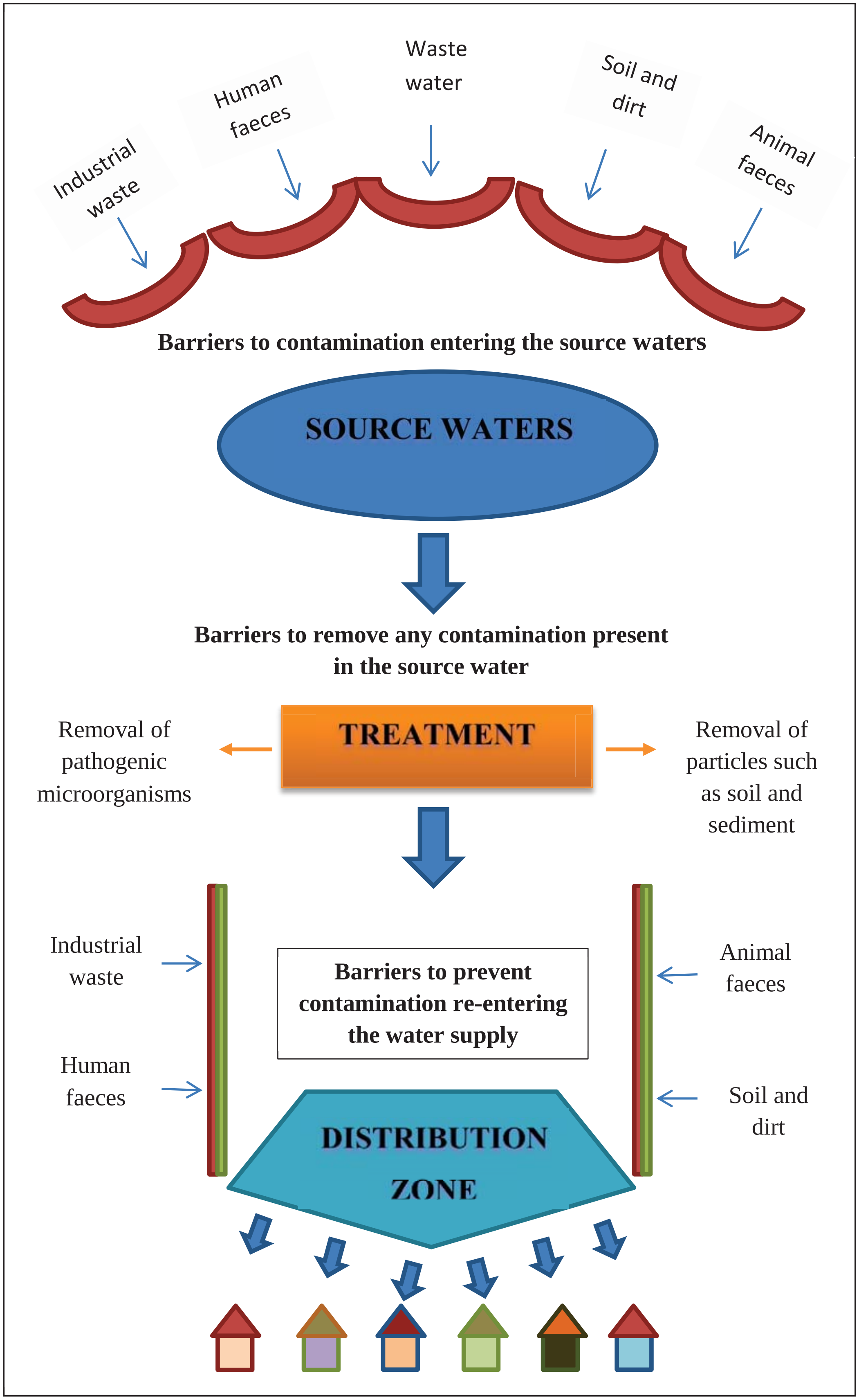

Figure 5. Diagram showing elements of the multiple barrier principle

3.2.2 Legislation

The main piece of legislation governing the reticulated supply of water is the Health (Drinking Water) Amendment Act 2007 which amended Section 69 of the Health Act 1956. This amendment Act specifies the requirements that reticulated supplies must legally meet to ensure that they are providing a potable supply of water. Since July 1st 2012 all large suppliers, those supplying more than 10,000 consumers, must register their supply on the Register of Drinking-water Supplies in New Zealand, they must monitor their water supply, and implement a public health risk management plan (PHRMP). Suppliers also have to ensure that they supply an ‘adequate’ supply of water and ‘take all practicable steps to comply with the DWSNZ (Health (Drinking Water) Amendment Act, 2007).

The Register of Community Drinking-water supplies in New Zealand provides information on community drinking-water supplies (those serving more than 25 people for more than 60 days a year) including the name of the community supply; the name of the owner and operator of the supply; and how many people use the supply. If more than 500 people use the supply then the Register also records the public health grading for the supply and any substances of public health significance in the supply requiring monitoring (Drinking Water for New Zealand, 2012a; MoH, 2005c).

A PHRMP is a tool used by suppliers to help them identify and reduce all of the possible health risks in a drinking-water supply. The supplier works through the full process of drinking-water supply from source to the consumer’s tap identifying possible situations that may lead to contamination. Actions are then determined that will either reduce or remove these risks (MoH, 2005c).

3.2.3 Drinking-water Standards for New Zealand 2005 (Revised 2008)

The DWSNZ has been written to protect public health. Maximum acceptable values (MAVs) for specific determinands allowed in drinking-water are set in the Standards along with compliance criteria, reporting requirements, and the remedial actions that must be taken in the event of a MAV transgression. Supplies have to meet compliance criteria at the treatment plant and in the distribution zone. The criteria that must be met for compliance with the Standards are specific to the size of the drinking-water supply, as well as to the type of source water and treatment method employed (MoH, 2008).

To reduce monitoring costs the determinands of public health significance have been placed into four Priority classes. Priority 1 determinands are those of greatest health significance and have to be monitored for in all community drinking-water supplies. The Priority 1 determinands are *E.coli* and the protozoa; *Giardia* and *Cryptosporidium*. Priority 2 determinands (P2) are those determinands that have to be monitored for in a particular supply, as they are present in the supply in concentrations greater than 50% of their maximum acceptable value (MAV). Priority 3 and 4 determinands do not have to be monitored for compliance (MoH, 2008).

To gain compliance with the DWSNZ 2005 (Revised 2008) drinking-water supplies have to meet compliance criteria for microbiological, chemical, cyanotoxin, and radiological contaminants. Bacterial compliance can either be achieved by testing for the indicator organism *E.coli*, or by showing that the treatment process meets designated performance criteria. For protozoal compliance, it must be shown that the treatment process can meet pre-defined performance specifications. Chemical and cyanotoxin compliance need only be demonstrated for those determinands that have been shown to be a problem in a particular supply and radiological contaminants are rarely a problem in New Zealand drinking-waters (Nokes, 2008a; Taylor, 2002).

3.2.4 Drinking-water quality in New Zealand

In the 2010-2011 reporting year, 78 per cent of New Zealanders (2.67 million people) with a registered drinking-water supply received drinking-water that was compliant with the bacteriological, protozoal, and chemical zone compliance criteria specified in either the DWSNZ 2000 or the DWSNZ 2005 (Revised 2008). There were, however, approximately 92,000 people in New Zealand with registered drinking-water supplies that received water that did not comply with the bacteriological compliance criteria in the Standards. The main reason for non-compliance was that the supply had more *E.coli* transgressions than were permissible. Non-compliance also occurred because suppliers did not take sufficient remedial actions when a transgression occurred. *E.coli* monitoring was inadequate or insufficient data was available (MoH, 2012a).

3.2.5 Microbiological water testing

Microbiological water testing in reticulated supplies is undertaken to demonstrate that water supplied to consumers is potable and that it meets the compliance criteria set in the Standards. Bacterial compliance criteria are set for water leaving the treatment plant and for water in the distribution zone. To meet these criteria drinking-water suppliers must monitor supplies for the indicator organism, *E.coli*. *If E.coli* is found to be present in any sample, response and remedial actions must be taken (MoH, 2008).

Monitoring frequency is dependent on the size of the population served by the supply and on whether monitoring is solely microbiological or combined with free available chlorine (FAC) monitoring. Samples must be taken at specified sites for water leaving the treatment plant and for water in the distribution zone. For water in the distribution zone, it is recommended that samples be taken before the consumer's tap at regular sampling points, such as at reservoirs or pumping stations (MoH, 2008).

3.2.6 Public health grading

The Ministry of Health also provides a public health grading for all registered supplies providing drinking-water to populations greater than 500 persons. Each supply is given a two-letter grading: the first letter is for the source and plant grading, and the second letter is for the distribution zone grading (Drinking Water for New Zealand, 2012c). This grading provides a publicly available indication of the quality of a water supply. The grading for each supply can be accessed on the Drinking Water for New Zealand web site (MoH, 2012a). There are currently no legislative requirements for grading and a supply need only be graded if it has been requested by a drinking-water assessor (J Graham, personal communication December 6, 2012).

3.2.7 Annual Report on Drinking-water Quality

Information regarding the compliance status of a drinking-water supply can be found in the Annual Report on Drinking-water Quality. The Annual report, published by the Ministry of Health, provides details of the protozoal compliance, zone bacteriological compliance, and chemical compliance status of a supply. The most recent report (2010/2011) also provides information concerning 'large' supplies compliance with the legislative requirements contained in the Health (Drinking Water) Amendment Act 2007 (MoH, 2012a).

3.3 Restrictor drinking-water supplies

In some areas of New Zealand, such as the Tasman District, some dwellings with a reticulated supply are supplied with a low-flow water supply that is delivered to the dwelling via a restrictor valve (TDC, 2012d). Restrictor valves reduce the flow-rate of the water in the network pipes and are set to ensure that a pre-determined amount of water is trickle-fed to a dwelling each day. To ensure that water supplied to the house is at a sufficient pressure and flow, dwellings with a restrictor supply usually have to store their water prior to use (MoH, 2010c).

3.3.1 Legislation

In New Zealand, the drinking-water supplier is responsible for the quality of the water supply up to the meter for full-pressure supplies and up to the restrictor valve for low-pressure supplies (Health (Drinking Water) Amendment Act, 2007). Once the water supply passes the meter or the restrictor the water supply becomes the responsibility of the property owner. The property owner is then legally obliged, under legislation contained in section 39 of the Health Act 1956 and section 123 of the Building Act 2004, to ensure that an adequate and potable supply of water is supplied to the dwelling.

A similar situation exists in the United Kingdom. Water is supplied from a rising main at full-pressure to the cold-water tap in the kitchen and to a cistern in the attic. Water from the cistern then feeds the hot water cylinder and the remaining taps in the house. Water quality is the responsibility of the supplier up to the stopcock on the boundary of the property. After this point water quality and the maintenance of all pipes and fittings becomes the responsibility of the homeowner (Gray, 2008).

3.3.2 Advantages

There are several advantages to low-pressure systems. Low-pressure household water systems are less noisy and burst water pipes are not as much of a problem compared to high-pressure systems (Gray, 2008). Low-pressure systems ensure that all households have a sufficient water supply during peak demand periods. Furthermore, households that have these systems are protected from loss of supply when water supply is cut-off, for example during times when repair work is being undertaken (Gray, 2008; MoH, 2010c).

3.3.3 Disadvantages

Owners of low-flow restrictor supplies have to install and maintain pipes, storage tanks, and sometimes pumps, to ensure that they have an adequate supply of water. Research has shown that household piping and household storage tanks can be a source of drinking-water contamination (Al-Bahry, Elshafie, Victor, Mahmoud, & Al-Hinai, 2011; Evison & Sunna, 2001; Lautenschlager et al., 2010; Pepper et al., 2004; Tokajian & Hashwa, 2004). A study undertaken in Tucson, Arizona tracked the changes in heterotrophic plate count (HPC) from the water source to the consumer's tap. HPC of source water at the chlorinated distribution site averaged 47 cfu/ml whereas HPC at the consumers' taps averaged 3,072 cfu/ml. The authors concluded that household pipes were the major source of bacteria in drinking-water (Pepper et al., 2004).

A similar study undertaken in Switzerland measured the effects of overnight stagnation on the microbiological quality of un-chlorinated drinking-water from ten households in Dübendorf. Samples were taken from the distribution network and from consumers' taps, after overnight stagnation. HPC were found to be from four to 580 times higher in stagnated water than in water samples that had been flushed for at least five minutes (Lautenschlager et al., 2010).

Routine water sampling of drinking-water at the kitchen tap has also shown that water supplies, delivered via a reticulated system, can be microbiologically contaminated. In New South Wales (NSW), Australia, the NSW Health Department monitors the quality of regional drinking-water supplies at the kitchen tap. Compliance is assessed by determining the number of samples in which *E.coli* is detected. The upper acceptable threshold for detection is two detections of *E.coli* per 100 samples (New South Wales Health, 2005; NHRMC & NRMMC, 2004). Results for all regional reticulated supplies in NSW for the six year period from 2001-2007 demonstrated that almost 40% (129/133) of these supply systems detected *E.coli* in more than 2% of samples taken (Cretikos et al., 2010).

Not only can microbiological changes occur in household pipes but changes can also occur in household storage tanks. Tokajian and Hashwa (2004) investigated the changes in microbiological quality of reticulated drinking-water that was stored in 1,000 L household water storage tanks. The reticulated water had been treated with filtration and UV light. A water-sampling schedule was set up to mimic ordinary household use and testing results showed that a significant increase in HPC was observed in the water after storage in the tanks.

Lack of maintenance can also be an issue with privately owned water supplies that have to store their water prior to use. Research undertaken both in New Zealand (Abbott et al., 2006; Thompson, 2011a) and overseas (Baguma et al., 2010; Richardson, et al., 2009; Rodrigo et al., 2010; Rutter, Nichols, Swan, & De Louvois, 2000; Said, Wright, Nichols, Reacher, & Rutter, 2003; Verrinder & Keleher, 2001) has shown that householders with private water supplies carry out minimal maintenance on their water supply systems. A study in New Zealand, conducted by Abbott et al. (2006), determined that 30% of 560 households with private rainwater supplies never cleaned their water tanks. In Australia, Rodrigo et al. (2010) found that water storage tank cleaning did occur, but only occasionally, with 50.4% of 325 households cleaning their tank one - five years previously and 31.9% cleaning their tank more than five years previously. These studies, however, have been conducted on households with private water supplies sourced from roof-collected rainwater, not on restrictor supplies supplied from a reticulated network supply.

3.4 Waterborne disease

3.4.1 Causes and effects

The greatest health risks associated with drinking-water are those that occur due to the ingestion of water contaminated with animal or human faeces (WHO, 2011). Faeces can potentially enter a water supply at any point in the supply network (Figure 5) and are a source of three types of pathogenic micro-organisms: bacteria (such as *Campylobacter* and *E.coli* O157:H7), protozoa (such as *Giardia* and *Cryptosporidium*), and viruses (such as norovirus) (MoH, 2005c, 2008). The ingestion of these pathogenic micro-organisms can cause both acute and chronic illnesses (WHO, 2011). Acute gastrointestinal illness (AGI) is usually self-limiting although it can, in extreme cases, lead to death. Chronic illnesses, such as irritable bowel syndrome and inflammatory bowel disease, can also sometimes occur in susceptible individuals (Ball, 2007; Moore, Black, Valji, & Tooth, 2010).

3.4.2 Endemic waterborne disease in New Zealand

Endemic disease is a disease that is constantly present within a region or area. New Zealand has relatively high rates of endemic waterborne disease (Ball, 2007; Moore et al., 2010). These high rates of endemic disease are believed to be due to the consumption of reticulated drinking-water that does not comply with the DWSNZ. There are an estimated 18,000 to 34,000 cases of endemic waterborne disease per year in New Zealand with more than half of these being attributable to protozoal disease (Ball, 2007; Moore et al., 2010). The cost of this waterborne disease to New Zealand is believed to be approximately $38.5 million per year (Moore et al., 2010).

3.4.3 Epidemic waterborne disease in New Zealand

Epidemic disease is distinguishable from endemic disease as epidemics are associated with outbreaks of disease that have a common source, location, or vehicle of infection (Tortora, Funke, & Case, 2013). Waterborne outbreaks do occur in New Zealand but most of these outbreaks have affected less than 100 people (MoH, 2012b). For example, in 2011 there were 45 waterborne outbreaks reported with a total of only 141 associated cases. Enteric protozoa (*Giardia* spp. and *Cryptosporidium* spp.) were found to be the most commonly reported cause of these outbreaks accounting for 60% (27/45) of the outbreaks in this time (Institute of Environmental Science and Research Ltd, 2012).

Most reported outbreaks in New Zealand are associated with small or community drinking-water supplies (Table 2). However, since 1984 there have been six reported outbreaks that have been linked to reticulated drinking-water supplies (Bartholomew, Mitchell, Ball, Williamson, & Gilpin, 2012; Brieseman, 1987; Cavill-Fowler, Haskell, & Brunton, 2012; Fraser & Cooke, 1991; Holmes, 1996;; Thorstensen, 1985). The largest of these outbreaks occurred in Queenstown in 1984. The town drinking-water supply was believed to have become contaminated with sewage from an over-flow pipe that discharged sewage into a creek near the drinking-water inlet. The supply was inadequately treated and an estimated 3,500 people contracted gastrointestinal illness after consuming this contaminated water supply (Thorstensen, 1985).

Table 2. Waterborne outbreaks in New Zealand from 1984-2012

Location, date	Causal agent	Cases	Supply type	Strength of association[a]	Water source and treatment
Queenstown, 1984	Unknown	(3,500)[b]	Reticulated	B, D	Lake water. Chlorination. (Thorstensen, 1985).
Ashburton, 1986	*Campylobacter*	19	Reticulated	B, D	River water and three wells. Chlorination on river supply; no treatment on well supply (Brieseman, 1987).
Canterbury, 1990	*Campylobacter*	42	Camp water supply	B, C	Four springs. Untreated (Stehr-Green, Nicholls, McEwan, Payne, & Mitchell, 1991).
Northland, 1992	Hepatitis A	30	Non-reticulated	B	Variety of supplies including roof-collected rainwater and creek water. Untreated. (Calder & Collison, 1992).
Lonsdale Park, Northland, 1992	*Campylobacter*	14	Camp water supply	B	Camp supply was untreated, roof-collected rainwater. Water was also consumed from a reticulated farm supply. (Jarman & Henneveld, 1993).
Dunedin	*Giardia*	50	Reticulated water supply	B, C	Two surface water sources: one treated with coagulation/flocculation, filtration, and chlorination; the other was just fluoridated (Fraser & Cooke, 1991)

Location, date	**Causal agent**	**Cases**	**Supply type**	**Strength of association**[a]	**Water source and treatment**
Auckland, 1993	*Giardia*	34		B	Thornton et al., 1993 (as cited in Ball, 2007)
Ashburton, 1996	*Campylobacter*	19	Reticulated	B, D	River water. Chlorination (Holmes, 1996).
Mt Hutt, 1996	Norovirus	58	Ski-field supply	B, D	Spring and two reservoirs. Filtration and UV (Brieseman, Holmes, Giles, & Ball, 2000).
Auckland, 1996	*Salmonella typhimurium*	4	Private roof-collected rainwater supply	A, D	Roof-collected rainwater. Untreated (Simmons & Smith, 1997).
Wainui, 1997	*Campylobacter*	6 (67)[b]	Camp drinking-water supply	A, C	Bore water. Untreated (Bohmer, 1997).
Te Aute College, 2001	*Campylobacter*	137	School drinking-water supply	A, D	Stream supply that was fed from a spring. The drinking-water supply was treated with fine filtration and UV. Water for the school pool, toilet flushing, and hot water was untreated (Inkson, 2002)
Banks Peninsula, 2004	*Shigella*	5 (18)[b]	Retreat drinking-water supply	B, D	Spring supply (Morrison & Smith, 2005).

Location, date	Causal agent	Cases	Supply type	Strength of association[a]	Water source and treatment
Nelson, 2004	*Campylobacter*	13	Camp supply.	B, D	Spring. Coarse filtration (Todd, 2005).
NZ ski field, 2006	Norovirus	218	Ski-field water supply.	A, D	Spring. Filtration and UV treatment (Hewitt et al., 2007).
Turoa ski field, 2009	Not identified	93	Ski-field drinking-water supply	B, D	Untreated, roof-collected rainwater (O'Connor, Wood, & Butters, 2010).
Runanga, West Coast, 2011	*Campylobacter*	4	Reticulated supply.	B, D	Untreated bore water (Cavill-Fowler et al., 2012).
Darfield, Canterbury, 2012	*Campylobacter*, possibly *Giardia*	13 (118)[b]	Reticulated supply	B, D	Deep well supplemented with river water when necessary. Chlorination (Bartholomew et al., 2012).
Hawkes Bay, 2012	*Campylobacter*	28	Camp supply	A, C	River water. Filtration and UV treatment (Rohleder & Calder, 2012).

[a]For explanation of strength of association see Appendix A
[b]Possible cases

3.4.4 Waterborne outbreaks worldwide

Leading causes of waterborne outbreaks vary worldwide. In a review of waterborne outbreaks undertaken by Hrudey and Hrudey (2007) from 1974 to 2007 *Cryptosporidium* was found to be the cause of most outbreaks, accounting for 20 of the 73 outbreaks; followed by *Campylobacter* (14/73), then *Giardia* (13/73). Enteric protozoan parasites were found to be the leading cause of waterborne outbreaks in the USA between 1971 and 2006 where they accounted for 18.3% of all waterborne outbreaks (Craun et al., 2010). However, in Norway, between 1984 and 2007, *Campylobacter* was found to be the main causative agent for waterborne outbreaks (Kvitsand & Fiksdal, 2010).

3.4.5 Reticulated supplies and waterborne outbreaks of disease

Although the consumption of reticulated water has been shown to be protective of human health (Eberhart-Phillips et al., 1997; Hoque, Hope, Scragg, & Kjellstrom, 2003) there are also incidences where the consumption of contaminated reticulated drinking-water has led to outbreaks of disease (Baldursson & Karanis, 2011; Craun et al., 2010; Hrudey & Hrudey, 2004, 2007; Schuster et al., 2005). These outbreaks can affect a large number of people in a relatively short period of time. An example of this occurred in Milwaukee, Wisconsin, in March-April of 1993. In this outbreak an estimated 400,000 people contracted acute gastrointestinal illness (AGI) from consuming the town drinking-water supply that was believed to be contaminated by *Cryptosporidium* (Mackenzie et al., 1994; Hrudey & Hrudey, 2007).

Reticulated supplies can become contaminated at any point in the supply network: at the source, the treatment plant, or in the distribution zone. For groundwater supplies, heavy rainfall can cause faecal contamination to be washed into the groundwater source (Nichols, Lane, Asgari, Verlander, & Charlett, 2009; Thomas et al., 2006). Periods of drought can cause cracks to occur in the ground which open up new water flow channels (Nichols et al., 2009). Human interventions, such as the placing of septic systems too close to groundwater sources, can also lead to source water contamination (Schmoll et al., 2006).

Untreated reticulated groundwater systems are of particular concern as these systems have no treatment barriers present to remove or reduce any contamination that may be present in the source water. In Norway, from 1984-2007, 26% of all waterborne outbreaks were attributed to untreated groundwater (Kvitsand & Fiksdal, 2010). In Finland from 1988-1999, nine of the 14 waterborne outbreaks recorded were associated with un-disinfected groundwaters (Miettinen, Zucheus, von Bonsdorff, & Vartiainen, 2001).

The importance of having an effective treatment system in the water supply chain is highlighted by the number of outbreaks that occur due to treatment system failures. In America, from 1971 to 2006, there were 338 waterborne disease outbreaks recorded in community water systems (those systems that supply water year round to at least 15 residents). Of these outbreaks, 154 (45.6%) were attributable to deficiencies in the treatment system (Craun et al., 2010). A review of worldwide waterborne protozoal disease outbreaks determined that there were 104 outbreaks associated with drinking-water systems over a period of 100 years from early last century until 2004. Deficiencies in water treatment systems were the most cited reason for these protozoal outbreaks. Deficiencies included poorly operated treatment systems, the use of insufficient barriers to ensure removal of contamination present in the source waters, and inadequate disinfection (Karanis, Kourenti, & Smith, 2007).

Contamination of water supplies can also occur in the distribution system. Studies have shown that the use of open storage reservoirs can lead to an increase in bacterial densities (Kerneis et al., 1995; LeChevallier et al., 1996; Lee et al., 2006). Biofilm formation in distribution pipes can lead to changes in microbiological water quality (LeChevallier et al., 1996). Contaminants can enter distribution pipes via breaks in the pipes, from cross-contamination, or from back-siphonage. Just over half of the 89 waterborne outbreaks caused by distribution deficiencies in the USA between 1971 and 1998 were found to be caused by cross-connections or back-siphonage (Craun & Calderon, 2001).

Not only can contamination of water supplies occur in the distribution network but drinking-water can also become contaminated in household plumbing (Lautenschlager et al., 2010; Pepper et al., 2004). A considerable number (n=55, 16.1%) of the 338 waterborne outbreaks occurring in community water supplies in the USA from 1971 to 2006 were due to deficiencies in household plumbing.

Examples of these plumbing deficiencies included problems with cross-connections and contamination of equipment used to distribute water, such as drink-mixing machines (Craun et al., 2010).

The cause of an outbreak may not be related to a problem in just one part of a water supply network but may be caused by multiple barrier failure. An example of an outbreak believed to be caused by multiple barrier failure occurred in Walkerton, Canada, in May 2000. The first barrier to fail occurred when the source water became contaminated with cattle manure. The second barrier to fail occurred when an insufficient dose of chlorine was added to the water supply at the water treatment station. This led to inadequately treated water being distributed to consumers. Lastly, monitoring of the supply was poor and the skill level of the water treatment plant operators was inadequate. The failure of these barriers led to an outbreak in which an estimated 2,300 people became sick and seven died after consuming contaminated drinking-water (Hrudey, Payment, Huck, Gillham, & Hrudey, 2003).

3.5 Water testing

3.5.1 Advantages

In New Zealand, microbiological monitoring of water supplies forms an important part of the multiple barrier framework in which drinking-water suppliers must work (Nokes, 2008a). Monitoring acts as a method of demonstrating that the water supplied to the consumer is safe to drink and that the mechanisms utilised to prevent and reduce contamination in the supply system are working effectively (Stevens, Ashbolt, & Cunliffe, 2003). Water testing is quick and easy to perform and can provide an indication of any changes in water quality over time (WHO, 2011).

3.5.2 Disadvantages

Microbiological monitoring, though, should not be relied on as a sole means of ensuring a safe supply of water as there are drawbacks to monitoring (Neumann et al, 2005; Nokes, 2008a, b). Samples taken are small (often only 100 ml) and may not be representative of drinking-water quality (Neumann et al., 2005). Samples only represent the water quality at that point in time and water quality can change quickly. Samples can take time to analyse and by the time the results of monitoring are known contaminated water may have already been supplied to consumers (Nokes, 2008a; Stevens et al., 2003; WHO, 2011). Testing water in the distribution zone does not always give a clear indication of the water quality at the household tap, as microbiological water quality can change in household pipes (Lautenschlager et al., 2010; Pepper et al., 2004). Monitoring also relies on the effectiveness of remedial actions, such as boil water notices, and these are not always effective (Angulo et al., 1997; Craun & Calderon, 2001).

A further disadvantage of water quality monitoring is that the presence of indicator organisms is not always correlated with disease outbreaks (Craun, Berger, & Calderon, 1997), with the presence of pathogens (Wu, Long, Das, & Dorner, 2011), or with endemic levels of gastrointestinal disease (Payment et al., 1993; Strauss, King, Ley, & Hoey, 2001). A review of waterborne outbreaks in America from 1983-1992 determined that coliform bacteria were only present in half of the water supply systems prior to an outbreak occurring (Craun et al., 1997). Furthermore, a study to determine the rates of gastrointestinal disease in families supplied with conventionally treated tap water determined that rates of gastrointestinal illness were not correlated with the presence of faecal indicators (Payment et al., 1993).

3.5.3 Indicator organisms

Testing for the presence of specific pathogens is often difficult, time-consuming, and expensive. To reduce the burden on suppliers of testing for specific pathogens, reliance is placed on testing for indicator organisms. Indicator organisms are not themselves pathogenic but provide an indication that contamination may be present in a water supply (MoH, 2005c). The ideal indicator should (MoH, 2005c; WHO, 2003):

- Be relatively quick, easy, and inexpensive to detect
- Be present when faecal contamination is present
- Respond to water treatment in a similar manner to the pathogens of concern
- Have similar survival rates in water as the pathogens of concern
- Be present in faeces in large numbers
- Not multiply in the environment
- Not be pathogenic

The DWSNZ 2005 (Revised 2008), along with the World Health Organisation (WHO), recommends the use of the indicator organism *E.coli* to demonstrate the presence or absence of faecal contamination (MoH, 2008; WHO, 2011). *E.coli* has been chosen as the indicator organism of choice as it is present in human and animal faeces in large numbers (Edberg, Rice, Karlin, & Allen, 2000; MoH, 2008) and does not usually multiply in a drinking water environment (Standridge, 2008). *E.coli* has also been shown to be the only coliform exclusively associated with a faecal source and it can be detected and enumerated easily and quickly (Edberg et al., 2000; Olstadt, Schauer, Standridge, & Kluender, 2007; Standridge, 2008; Tallon, Magajna, Lofranco, & Leung, 2005).

Although *E.coli* is the indicator organism of choice in New Zealand (MoH, 2008), and in other countries such as Australia (NHRMC & NRMMC, 2004) and Canada (Health Canada, 2006), there are some drawbacks to its use. *E.coli* is not always a reliable indicator of the presence of protozoa and viruses as these microorganisms can survive for longer periods in water than *E.coli* (Stevens et al., 2003). In unusual and specific situations it has been shown that *E.coli* can multiply and grow in aquatic environments (Beauchamp, Simao-Beaunoir, Beaulieu, & Chalifour, 2006; Ishii, Ksoll, Hicks, & Sadowsky, 2006; Tamplin, 2003). Furthermore, there can be some confusion for the public arising from the fact that *E.coli* has both pathogenic and harmless variants (Standridge, 2008).

In New Zealand, total coliforms can be used as an indicator in place of *E.coli*. However, their use is not recommended (MoH, 2008) as total coliforms are natural inhabitants of the soil and the environment and are not always indicative of faecal contamination (Edberg et al., 2000; Stevens et al., 2003**).** Coliforms have also been shown to grow in the distribution system and to be a natural inhabitant of biofilms in water distribution pipes (LeChevallier, 1990). Furthermore, the presence of coliforms in drinking-water supplies is not always correlated with disease outbreaks. A study in the USA, that investigated the relationship between disease outbreaks and the presence of coliforms in a water supply, determined that coliforms were only detected in half of the supply systems before an outbreak. Coliforms were usually present for waterborne outbreaks caused by bacteria and viruses but were rarely present when outbreaks were caused by protozoa (Craun et al., 1997).

3.5.4 Restrictor supplies

It is currently unclear whether owners of restrictor supplies should test their drinking-water. Owners of private drinking-water supplies are advised to have their drinking-water tested at least once every six months (MoH, 2005d) and suppliers of reticulated supplies have to test water in the distribution zone at a frequency specified in the DWSNZ (MoH, 2008). However, restrictor supplies, supplied from a reticulated supply, are a combination of the two supply types; reticulated and private. In theory, the water supplied via a reticulated restrictor supply should have been tested in the distribution zone by the water supplier and the water should be compliant with the microbiological criteria stated in the DWSNZ. However, as research has shown that water quality can change in distribution pipes (LeChevallier et al., 1996; Payment & Robertson, 2004), household pipes (Lautenschlager et al., 2010; Pepper et al., 2004), and in storage tanks (Evison & Sunna, 2001; Tokajian & Hashwa, 2004) there appears to be no guarantee that drinking-water reaching the kitchen tap will still be potable.

Research undertaken on the water testing behaviour of owners with private water supplies indicates that even when water testing is recommended it is seldom carried out at the recommended frequency. In Ontario, Canada, where responsibility for water testing of private supplies lies with the owner of the supply, provincial guidelines recommend that microbiological water testing should be carried out at least three times a year (Jones et al., 2006). However, research undertaken by Jones et al. (2006) found that only 8% of 239 respondents surveyed with a private water supply had had their water tested with this frequency and a further 21% of all respondents had never had their water tested.

3.6 Water treatment devices

The use of home water treatment devices, also known as ‘point-of-use’ treatment systems, is becoming increasingly popular (Chaidez & Gerba, 2004; Gray, 2008). A cross-sectional survey undertaken in British Columbia, Canada determined that 47% of households surveyed used in-home treatment devices (Jones et al., 2007). This result correlated with surveys, undertaken by Statistics Canada in both 2007 and 2009, which showed that 54% and 51% of respondents respectively treated their water with in-home treatment devices prior to consumption (Statistics Canada, 2009).

There is a diverse range of in-home (or household) water treatment devices available such as: kettles (for boiling water), jug filters, ceramic candle filters, cartridge filters, reverse osmosis, ultrafiltration, chlorination, and ultra-violet light treatment systems (Davey Water Products, 2009; MoH, 2005c). The choice of device installed appears to vary, with householders often using more than one device at a time (Jones et al., 2006). Statistics Canada determined that approximately 35% of households with a municipal supply used jug filters compared to 15% of households with a private supply. The most commonly used device for private supplies was a filter and purifier fitted on the main supply pipe (Statistics Canada, 2009). In a study undertaken in New Zealand, to determine the microbiological quality of roof-collected rainwater, filtration was also found to be the most popular type of water treatment employed with 10% of participants using a filtration system in their household water supply.

The reasons for installing a water treatment device seem to vary but improvements in the aesthetic quality and safety of water appear to be the leading reasons for the use of these devices (Jones et al., 2006). A study undertaken to determine the public perception of drinking-water from private supplies in Ontario, Canada demonstrated that the main reason for installing a water treatment device, cited by 75% of respondents, was to reduce bacterial concentration. Nearly half of respondents stated that they had fitted a device to improve the aesthetic quality of their water, in particular the smell and taste (Jones et al., 2006). A survey undertaken by Levallois, Grondin, & Gringras (1999), to evaluate consumers' attitudes to the taste of tap water, determined that improvement in taste was also mentioned as being the main reason for installing a water treatment device.

Point-of-use treatment devices must be maintained regularly as they can act as a source of microbial contamination (Gray, 2008; MoH, 2005c) which leads to a reduction in drinking-water quality. Chaidez and Gerba (2004) compared the microbiological quality of drinking-water supplied from a point-of-use water activated carbon treatment device to that of tap water without a point-of-use device. Average concentrations of HPC were more than 10 times higher in point-of-use treated water than untreated water. Similarly, coliform counts were 20 times higher in the treated water.

3.7 Consumers' knowledge and perceptions

3.7.1 Knowledge of water quality

The public health grading and compliance status of reticulated supplies in New Zealand is published in documents such as the Annual Report on Drinking-water Quality and on the Drinking-water New Zealand web site (Drinking-water for New Zealand, 2012a; MoH, 2012a). Publication of this data provides consumers with information regarding the quality of their water supply. Other countries, such as the USA, are also legally obliged to report to consumers on drinking-water quality (Johnson, 2003).

It is currently unknown, though, whether consumers are either aware of these water quality reports or if they understand their content. Johnson (2003), in a survey to determine the effects of drinking-water quality reports on consumer attitudes, determined that consumers have difficulty reading and understanding water quality reports. Many respondents found it difficult to identify whether a substance violated a standard even when the violation had been made obvious in the report. Moreover, respondents' evaluations of water quality did not change after reading reports. Respondents attitudes to water quality appeared to be more affected by their generic beliefs regarding items such as environmental issues and their regard for the reliability of the water supply company, than they were by the content of the water quality reports.

3.7.2 Perceptions of water quality

Studies conducted overseas to determine what affects the public perception of the drinking water quality of reticulated supplies have demonstrated that the perception of quality results from the interaction of a multitude of different factors (Doria, 2010; Doria, Pidgeon, & Hunter, 2005, 2009; Dupont, Adamowicz, & Krupnick, 2010; Levallois et al., 1999). Organoleptic properties, especially flavour, appear to have the most influence on water quality perception. Other factors such as a person's attitude to chemicals, their risk perception of drinking water, and information obtained from the media, family, and friends were also found to affect a person's perception of water quality (Doria, 2010).

3.8 Conclusion

To summarise, it can be seen that although problems can occur in the supply of reticulated drinking-water, the benefits of these supplies far outweigh any potential problems. The use of multiple barriers in the supply network, to either prevent or reduce contamination levels, provides an increased level of assurance that drinking-water reaching the consumer will be potable. When one or more of these barriers fail, outbreaks can occur that affect a large number of people in a short period of time. However, to date, outbreaks of this type have been limited in New Zealand and most consumers of reticulated drinking-water in this country receive a potable supply of water.

4 Research hypothesis, aim, and objectives

4.1 Hypothesis

The microbiological quality of drinking-water at the kitchen tap was the same for dwellings with an on-demand, metered water supply compared to dwellings with a restricted, low-flow supply, where both dwelling types were supplied from the Richmond urban water supply scheme.

4.2 Aim

The microbiological quality of drinking-water from dwellings with an on-demand, metered water supply was compared to the microbiological quality of drinking-water from dwellings with a restricted, low-flow supply, where both dwelling types were supplied from the Richmond urban water supply scheme. *E.coli* and total coliforms were used as indicators of water quality and the results obtained were compared to the microbiological standards set in the DWSNZ 2005 (Revised 2008) in order to determine compliance with these Standards.

4.3 Objectives

The objectives of this study were to:

1. Determine whether residents of dwellings supplied with drinking-water from the Richmond urban water supply scheme supplemented their drinking-water supply with water from another source and, if so, how frequently this occurred
2. Determine what water treatment options, if any, were employed by residents of both urban and semi-urban dwellings
3. Determine if water testing had been carried out by residents of both urban and semi-urban dwellings
4. Ascertain residents perceptions of their drinking-water quality
5. Ascertain if residents, of both types of dwellings, were aware of the data published concerning the microbiological quality of the Richmond urban water supply scheme in the Register of Community Drinking-water Supplies in New Zealand and in the Annual Review of Drinking-water Quality in New Zealand.

6 Ascertain what type of water storage system had been employed by owners of dwellings with an on-demand water supply, that supplemented their drinking-water supply from another source and by owners of dwellings with a restricted, low-flow supply

7 Ascertain whether owners of dwellings with an on-demand water supply, that supplemented their drinking-water supply from another source and owners of dwellings with a restricted, low-flow supply, carried out any maintenance work on their drinking-water supply systems.

5 Methodology

5.1 Researcher's worldview

This research project has been undertaken using a quantitative methodology with the use of quantitative methods of research. The use of a quantitative methodology and quantitative methods corresponds with the post-positivist worldview held by the researcher. This worldview is held by people who believe that reality exists, but it can never be fully understood (Guba, 1990). They believe that research should be undertaken deductively and that theories should be stated at the start of the research project. Research should be undertaken in an objective manner using experimental methods (Creswell, 2009; Guba, 1990) and hypotheses made should be tested quantitatively and rejected if found to be untrue (Creswell, 2009).

5.2 Justification for methods employed

5.2.1 Cross-sectional survey

A cross-sectional survey was undertaken in this research project. This particular method of research was used as it provided a relatively quick, cost efficient method of collecting a large amount of data in a short period of time (Alreck & Settle, 2004; Babbie, 2010). Surveys are flexible and versatile and can be tailored to suit the needs of both the surveyor and the respondent (Alreck & Settle, 2004). The data generated by a survey is standardized and can be statistically analysed (Rea & Parker, 2005). Surveys are also a good method of providing quantitative information about a population (Creswell, 2009).

5.2.2 Population

The population for this survey was defined as all of the households in the Richmond area of the Tasman District, New Zealand, that were supplied with drinking-water from the Richmond urban water supply scheme.

The Richmond area of the Tasman District was purposively chosen for this survey for several reasons:

1 At the time of undertaking this survey, the Richmond urban water supply was an untreated and non-chlorinated supply (TDC, 2012d).

2 The Richmond urban water scheme supplied drinking-water to two types of dwelling: urban dwellings with an on-demand, mains pressure, metered supply and semi-urban dwellings with a restricted, low-flow supply (TDC, 2012d). Supply of water from the same water scheme to two different types of dwellings allowed microbiological water quality comparisons to be made between these two dwelling types.

3 The Richmond urban water scheme was supplied to approximately 5,000 on-demand, metered properties and to 100 restricted, low-flow properties (TDC, 2009, 2012d).

4 The Richmond area was in close proximity to the researcher's home which reduced transport costs and made access to participants easier.

5 The researcher lived in a dwelling that was supplied with a restricted, low flow drinking-water supply from the Richmond urban water scheme. The researcher was familiar with both the Richmond urban water scheme and with the complexities of owning a restricted water supply.

5.2.3 Sampling

Sample size

A sample size of 100 dwellings was specified by the course supervisors as being an adequate number of dwellings to sample in the time available. Of these 100 dwellings; 50 were to be on-demand, metered dwellings and 50 were to be dwellings with a low-flow, restricted supply.

Sampling frame

The sampling frame for this survey was compiled from three sources of information:

1. A water supply map provided by MWH New Zealand Ltd (Figure 3). This map showed the location of dwellings in Richmond that were supplied with water from the Richmond urban water supply scheme.
2. The Tasman District Council's rates information web page (TDC, 2012c). This site provided addresses of all the dwellings in Richmond that paid water rates and whether the dwelling was on a metered or a restrictor supply.
3. The Top of the South Maps web site (Top of the South Maps, 2012). This site provided details of properties in Richmond and confirmed whether the property was supplied with a metered or a restrictor drinking-water supply.

Sampling method

Stratified random sampling was used in this survey. Random sampling reduced sampling bias by ensuring that each property in the population had an equal chance of being selected for this survey (Babbie, 2010). The sample was stratified in order to obtain equal sample numbers of dwellings with a metered supply and dwellings with a restrictor supply.

5.2.4 Use of questionnaire

An interviewer-administered questionnaire was chosen as a survey instrument for this study (Appendix B). A questionnaire was used as it provided a relatively low cost method of obtaining information from a lot of people in a short period of time (Gillham, 2000). Standardisation of questions made analysis of closed questions easy and provided data for hypothesis testing (Gillham, 2000). The use of open ended questions allowed respondents to answer some questions in their own words. This produced some unanticipated answers and also permitted respondents to share their 'real views' (Fowler, 2009).

5.2.5 Use of an interviewer

An interviewer was used to administer the questionnaire as this method of administration would have increased response rates, reduced non-response bias, and ensured that hard-to-reach populations could be contacted (Fowler, 2009). An interviewer removed the literacy problems that could occur when participants are unable to read or understand a particular question (Bowling, 2009).

In this study the researcher acted as the interviewer. The use of the researcher as an interviewer enabled a rapport to be built with participants and ensured that all questions were understood by participants (Kumar, 2005). The researcher had written the questionnaire and was familiar with its wording. The researcher was also able to supplement the data collected in the questionnaire by undertaking observations of the environment (Babbie, 2010). This was considered important in this survey as further information could be collected by visually inspecting participants' water storage systems.

Interviewer bias was minimized by using the same interviewer (the researcher) for all interviews. The researcher had undertaken previous similar surveys and ensured that the wording and order of the questions was the same for each participant. All open-ended questions were recorded 'verbatim'.

To reduce social desirability bias participants were assured that their responses to the survey would remain anonymous. Participants were also assured that there were no 'right' or 'wrong' answers.

5.2.6 Laboratory facilities

Water samples were analysed at the laboratory set up at the researcher's dwelling (Appendix C). The use of a home laboratory was justified because:

- Costs were reduced. The nearest registered laboratory, the Cawthron Institute, was a 40 km round trip from the researcher's home and this laboratory had a $50.00 fee to analyse each water sample (Cawthron Institute, 2012).
- Sampling was facilitated. Sampling could be undertaken at times that suited participants and the researcher. Delays from time of sampling to time of analyses were minimized.
- Skills. The researcher had the relevant qualifications and experience to undertake the analyses.
- Reliability. Reliability of the analyses was increased as the same person was undertaking all of the sampling and water sample analyses.

5.2.7 Colilert®-18 method

The Colilert®-18 method for the enumeration of *E.coli* and total coliforms was used in this survey. Colilert®-18 is an APHA approved enzyme substrate coliform test (American Public Health Association [APHA], 2012) and is an approved referee method in the DWSNZ 2005 (Revised 2008) (MoH, 2008). Colilert®-18 is also an easy and quick test to perform (IDEXX, 2012a; Olstadt et al., 2007).

Colilert®-18 relies on the action of enzymes present in total coliforms and *E.coli*. These enzymes act on specific substrates present in the Colilert®-18 reagent to produce colour changes in the water sample. Total coliforms are present if the water sample turns yellow and *E.coli* is present if the sample fluoresces under ultraviolet light, after incubation (IDEXX, 2012a).

The nutrient indicators used in Colilert®-18 are ONPG (ortho-nitrophenyl-β-D-galactopyranoside) and MUG (4-methyl-umbelliferyl-β-D-glucuronide). Total coliforms produce the enzyme β-galactosidase, which acts on the ONPG to release a visible yellow pigment. As well as producing β-galactosidase, *E.coli* also produces β-glucoronidase, which metabolises MUG to produce a pigment that fluoresces under a long wave (365 nm) ultraviolet light (IDEXX, 2012a).

5.2.8 Pilot study

A pilot study was undertaken to ensure that the questions in the questionnaire could be understood by participants. A total of eight purposively chosen participants, known to the researcher, were interviewed: four participants with a metered drinking-water supply and four participants with a restrictor drinking-water supply. The participants were asked to provide feedback on their level of understanding of the questions in the questionnaire and on the order of the questions. Subsequent to the pilot test a few minor amendments were made to the wording of two questions. The order of the questions remained unchanged. The participants that took part in the pilot study were excluded from the main survey.

5.2.9 Ethical considerations

This research project was evaluated by peer review and judged to be low risk. The researcher was responsible for the ethical conduct of this research. If participants had any concerns about the ethical conduct of this research that they wished to raise with someone other than the researcher, they were advised to contact Professor John O'Neill, Director, Research Ethics, Massey University, telephone 03 350 5249, email: humanethics@massey.ac.nz. Participation in this study was entirely voluntary and participants had the right to withdraw from the study up until September 3rd 2012. All data recorded has been treated as confidential and this report, as well as any publications produced from this report, contains no information by which any participant can be identified.

5.2.10 Reliability

To increase the reliability of the survey the questionnaire used was adapted from questionnaires used in previous surveys (Abbott et al., 2006; Fleming, 2000; Thompson, 2011a, 2011b). The questionnaire was administered to all participants by the same interviewer. The interviewer read the questions as written in the questionnaire, ensuring that the wording and order of questions was the same for each participant. A pilot study was also undertaken to ensure that the wording of the questions in the questionnaire was adequate and could be understood by respondents.

5.2.11 Validity

Internal validity of the questionnaire was increased by making sure that all the questions were understood by the respondents and by ensuring that the questions were relevant to the respondents (Suskie, 1996).

External validity of this research project was increased, by using a random sampling procedure, so that any dwelling in the population had an equal chance of being selected in the survey.

The validity of the water sampling analyses was increased, by undertaking ten dual water sample analyses with the Cawthron Institute (Appendix D).

6 Sampling and data analysis

6.1 Population

The population for this study was defined as all of the households in the Richmond area of the Tasman District, New Zealand, that were supplied with drinking-water from the Richmond urban water supply scheme.

6.2 Sampling

Sampling for this research project was undertaken during May, June, and July 2012. To obtain a stratified random sample for dwellings with a restrictor supply the location of restrictor properties was found using the map supplied from MWH New Zealand Ltd (Figure 3). Restrictor supplies were marked in blue and then highlighted with pink on this map. Top of the South Maps was then used to determine the street names and addresses of these properties (Top of the South Maps, 2012). The address of each property was then entered into the Tasman District Council's rates webpage to confirm that the property was supplied with a restrictor water supply (TDC, 2012c). Once confirmed, the address of each dwelling with a restrictor supply was entered into Excel. The *Randbetween* function was utilised to randomly number each dwelling. The properties were then ordered from lowest to highest random number and the 50 properties with the lowest random number were selected for participation in this survey.

A similar method was utilised to form a simple random sample of metered properties. Top of the South Maps was used to find the street names of all the properties marked in dark blue on the MWH New Zealand Ltd map that were supplied with drinking-water from the Richmond urban water supply scheme (Top of the South Maps, 2012). The name of each street supplied with Richmond urban water was entered into the Tasman District Council rates web page to find the addresses of all properties paying metered water rates on these streets (TDC, 2012c). The address of each dwelling was entered into Excel. Any commercial properties known to the researcher were not entered into Excel. The *Randbetween* function was utilised to randomly number each dwelling. The properties were then ordered from lowest to highest random number and the 50 properties with the lowest random number were selected for participation in this survey.

Once random sampling had been undertaken, the 100 randomly chosen properties were grouped by location into four groups. This grouping of properties facilitated sampling by reducing transport time and costs.
The dwellings that had been randomly chosen were visited during daylight hours to determine if the owner of the dwelling was willing to participate in this study. Evening visits (visits after dark) were only undertaken if prior contact had been made with the participant to arrange a convenient time.

6.3 Interview procedure

On arrival at the dwelling, the researcher ensured that she was talking with an adult in the household (person over the age of 18). The research survey was explained to the householder and they were then asked if they would like to participate in the survey. If the householder was willing to take part in the survey, an information sheet (Appendix E) was given to the householder. The householder was then asked to sign a participant consent form (Appendix F). Once consent had been obtained, the participant was interviewed using the interviewer administered questionnaire (Appendix B).

The questionnaire used in this survey was adapted from questionnaires used in previous surveys undertaken by the researcher (Abbott et al., 2006; Fleming, 2000; Thompson, 2011a, 2011b). The questionnaire consisted of predominantly closed questions with multiple, or single response tick boxes (Appendix B). Questions asked related to the participants' knowledge and use of their drinking-water supply. Further questions relating to water storage systems were asked of participants with a restrictor water supply. Open-ended questions were also included to elicit more in-depth answers from respondents. A five point Likert scale was used for questions concerning participants' perceptions of their water supply. Perceptions of taste, colour, odour, and safety of water supply were rated from very good to very poor. The questionnaire was ordered in a logical progression. The initial questions asked were designed not only to engage the participant but also to ensure that the participant felt comfortable with the interview process. Demographic data and more personal questions were asked towards the end of the interview process.

After the interview, a water sample was taken for analysis from the kitchen tap.

If the dwelling to be visited was a commercial dwelling rather than a domestic dwelling, the address was removed from the list and the next lowest numbered property on the list was sampled instead.

If the householder declined to take part in the survey, their address was removed from the sampling list and the next lowest numbered property on the list was sampled instead.

If the householder was not present on the first contact visit, the property was visited once more at a different time and day. If, after two visits no contact had been made, the property was removed from the sampling list and the next lowest numbered property on the sampling list was sampled instead. A log was kept showing the time and date of all properties visited along with the outcome of each visit (Appendix G).

6.4 Water sampling

At the end of each interview a water sample was collected aseptically from the cold water tap in the kitchen. A sample was also taken from any specific filter taps, such as under-bench filters, used in the kitchen for drinking-water.

A 250 ml sterile plastic bottle was labelled with name of participant, identification code, type of tap sampled; date and time of sampling. Protective gloves were put on prior to sampling from the tap. The tap to be sampled was then disinfected with an alcohol wipe (70% alcohol). The tap was turned on to full flow for two minutes. After this time, the tap flow was reduced. To collect the sample, the cap was carefully removed from the water sample bottle and held in one hand, facing downwards. The bottle was held in the other hand and filled with a water sample. Care was taken to not touch the inside of the bottle cap and the inside of the sampling bottle. Immediately after filling the sample bottle the cap was replaced. The sample bottle was placed in a chilly bin with cool packs and taken to be analysed at the laboratory (Appendix C). Analysis of each sample occurred within six hours of sampling.

6.4.1 Analysis of samples

Samples were analysed for total coliforms and *Escherichia coli* using the Colilert®-18 Quanti-Tray®/2000 method (IDEXX Laboratories, Westbrook, Maine, United States) within six hours of sampling (IDEXX Laboratories, 2012a, 2012b). Quanti-

Trays®/2000 and sterile graduated 120 ml plastic bottles were labelled with the time, date and sample ID numbers. A 100 ml of the drinking-water sample was placed aseptically into the 120 ml sterile sample bottle along with one package of powdered Colilert reagent. The water and reagent were mixed by shaking and then poured into a 97-well Quanti-Tray®/2000. The tray was mechanically sealed in a Quanti-Tray® sealer and incubated at 35.0^{o}C ± 0.5^{o}C for 18 hours. The temperature of the incubator was recorded prior to placing a sample in the incubator and prior to removing the sample from the incubator.

After 18 hours of incubation the Quanti-Tray®/2000 was removed from the incubator and inspected for colour change. Yellow wells which were as yellow or yellower than the comparator indicated the presence of total coliforms. The number of yellow wells was counted and the coliform count was determined by referring to the 97-well most probable number (MPN) table. The Quanti-Tray®/2000 was then viewed in a darkened room by placing it under and within 12 cm of a 365 nm ultraviolet light. Blue fluorescence indicated the presence of *Escherichia coli*. The number of fluorescent blue wells present was counted and the *E.coli* count was determined by also referring to a 97-well MPN table. Wells with no yellow colour were considered negative for total coliforms and wells with no fluorescence were considered negative for *E.coli*.

Control cultures were put up during the study. *E.coli* (NZRM 916 - nutrient agar culture) was used as the complete positive control (yellow and blue fluorescent wells). *Klebsiella pneumoniae* (NZRM 482 - nutrient agar culture) was used as the partial positive control (yellow wells but no fluorescence) and *Pseudomonas aeruginosa* (NZRM 981 - nutrient agar culture) was used as the negative control (no yellow wells and no fluorescence). A colony of each bacterial strain was transferred, using a sterile inoculating loop, to 5.0 ml of sterile distilled water and mixed well. A one microliter loop full of this mixture was transferred to a 100 ml bottle of sterile distilled water and mixed with one package of Colilert®-18 reagent powder. The mixture was shaken until the reagent had dissolved and it was then poured into a sterile 97-well Quanti-Tray®/2000. The Quanti-Tray®/2000 was sealed and then incubated at 35.0 ± 0.5^{o}C for 18 hours. After 18 hours the trays were inspected for yellow colour and fluorescence (Figure 6).

P.aeruginosa

K.pneumoniae

E.coli

E.coli under UV lamp

Figure 6. Quanti-Tray® control cultures after incubation

6.5 Communication of Results

Participants were phoned and provided with a written copy of the microbiological results of their drinking-water samples within 72 hours of sampling. The results stated the total coliform and *E.coli* counts of the participant's water sample. Compliance status of the water sample with the microbiological criteria in the DWSNZ 2005 (Revised 2008) was also given (Appendix H). Participants with a non-compliant supply were provided with a copy of the Ministry of Health booklet 'Household Water Supplies' (MoH, 2009c). In due course, a summary of the project findings will be sent to the following persons: all participants; Evan Mackenzie, the Drinking-Water Assessor for the Nelson Marlborough District Health Board; Jeff Cuthbertson, the Tasman District Council Utilities Asset Manager; and to Dr Gillian Bullock, Water Scientist, MWH New Zealand Ltd.

6.6 Data analysis

The results for dwellings with a restrictor supply have been separated into two categories: restrictor-only and restrictor-supplemented supplies. Restrictor-only supplies were those dwellings that did not supplement their water supply with water from another source and restrictor-supplemented supplies were those dwellings that did supplement their water supply with water from another source.

All the data collected has been input into and analysed using SPSS Version 20. Graphs and tables have been generated using Excel. Counts of *E.coli* and total coliforms have been recorded and grouped into three categories: <1 cfu/100 ml, 1-9 cfu/100 ml, and ≥ 10 cfu/100 ml. Justification for these categories was based on information provided in the DWSNZ 2005 (Revised 2008) (Appendix I). Compliance with the microbiological criteria stated in the DWSNZ 2005 (Revised 2008) has been determined.

Data recorded relating to supplementary supplies, system design, maintenance undertaken, and use of treatment systems has been recorded. Graphs have been generated using Excel. Open-ended questions have been coded. Main themes have been identified and assigned a code. The frequency with which each code appeared has been counted and tabulated. Results have been reported in a tabulated form and, where appropriate, examples have been given of verbatim responses. Further information on statistical analyses performed has been included in Appendix J.

7 Results

A full copy of all data recorded in this survey has been included with this thesis on a CD-ROM.

This section contains the results for all metered and all restrictor-only dwellings, along with the microbiological water quality results for restrictor-supplemented dwellings. Tables of data for all graphs in this section are included in Appendix K. Results for restrictor-supplemented supplies are contained in Appendix L. Supplementary tables of data for graphs in Appendix L are included in Appendix M.

7.1 Response rates

To obtain a random sample of 50 dwellings with a metered supply a total of 104 households were contacted. Of these 104 households; 50 agreed to take part in the survey, 28 were not at home, and 26 declined to take part in the survey. This gave a response rate of 65.8% (50/76).

To obtain a random sample of 50 dwellings with a restrictor-only supply a total of 63 households were contacted. Of these 63 households; 50 households agreed to take part in this survey and had a restrictor-only supply; 11 households agreed to take part but had a restrictor-supplemented supply; one dwelling was unoccupied, and one householder declined to take part in the survey. This gave a response rate for restrictor-only dwellings of 98% (50/51).

7.2 Demographics

7.2.1 Details of participants

There were 35 female and 15 male participants with a metered supply and 29 female and 21 male participants with a restrictor-only supply. Participant gender was not significantly different between supply types ($\chi^2 = 1.563$, $p=0.211$).

Participants' age varied from 30 to 60+ years old with most participants, for both metered and restrictor-only dwellings, being in the 60+ age category (Figure 7). To ensure that all cell counts were five or greater, the data was grouped into three groups before the chi squared analysis was performed: 15-49, 50-59 and 60+ years.

There was no significant difference in age of participants between supply types (χ^2=0.405, p=0.817).

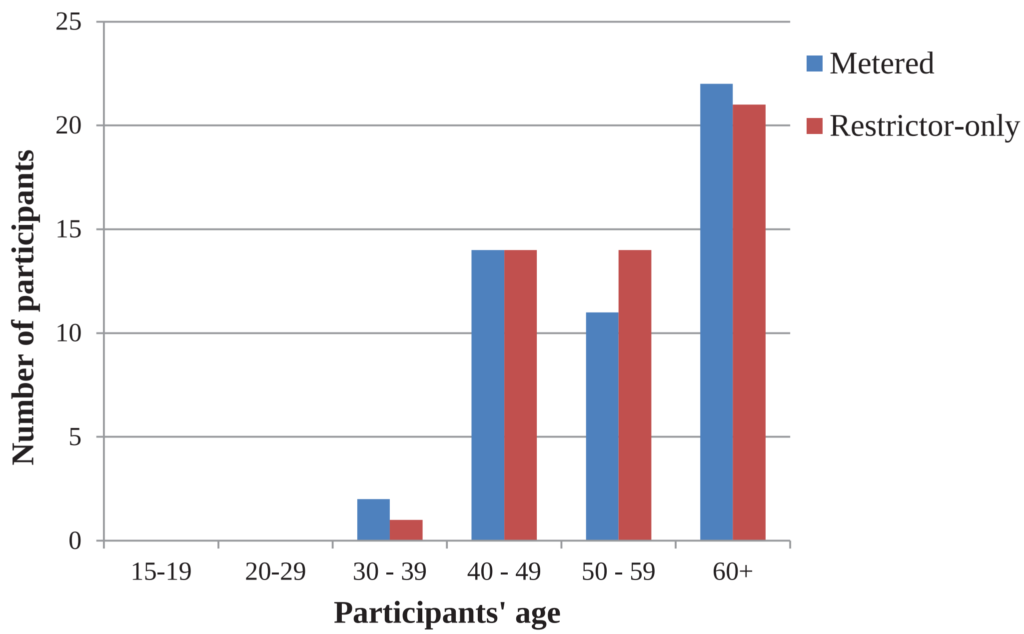

Figure 7. Participants' age for participants with a metered or a restrictor-only water supply

Forty three participants with a metered supply and 47 with a restrictor-only supply identified with European ethnicity. Two participants with a metered supply and none with a restrictor-only supply identified with Maori ethnicity. A total of four participants with a metered supply and three with a restrictor-only supply stated that they were of 'other' ethnicity. Prior to statistical analysis, ethnicity categories were placed into two groups: Maori and 'other' formed one group and European the other group. Using a Fisher's exact test, ethnicity for participants with a metered supply was found to be similar to that of participants with a restrictor-only supply (p=0.200). One cell had a count of less than five.

Occupation of all participants is shown in Figure 8. The most common occupation group for participants with a metered supply was 'retired' and for participants with a restrictor-only supply was 'professional'. For statistical analysis three categories were formed: home executive and retired; professional; and non-professional workers (the other four categories). Occupation of participants with a metered supply was significantly different to occupation of participants with a restrictor-only supply with more participants with a restrictor-only supply stating that they were professionals compared to participants with a metered supply (χ^2 =6.892, p=0.032).

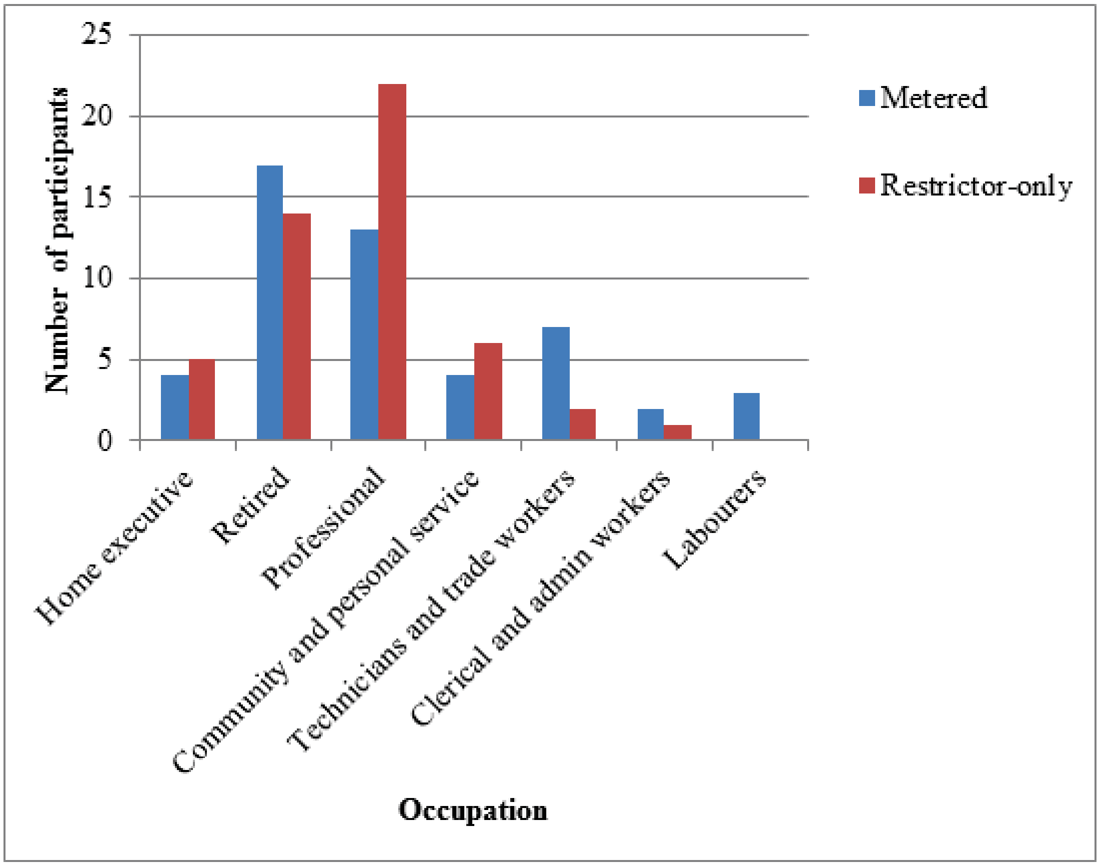

Figure 8. Occupation of participants with a metered or a restrictor-only water supply

Length of time lived at dwelling varied from less than one year to more than 10 years. Fifty eight per cent of participants with a metered supply and 70% of participants with a restrictor-only supply had lived at their dwelling for more than five years. There was no significant difference in the length of time that participants with a metered supply compared to participants with a restrictor-only supply had lived at their dwelling (χ^2 = 4.348, p=0.226).

Forty three participants with a metered supply and 49 with a restrictor-only supply owned their own dwelling. The other participants either rented their dwelling or the participants did not respond. A Fisher's exact test showed that there was no significant difference in home ownership between participants with a metered water supply compared to participants with a restrictor-only water supply ($p=0.108$). One cell count was less than five.

7.2.2 Details of dwellings

Participants with a metered supply lived in urban Richmond with 47 participants having a land area of <4000 m^2 and two participants having a land area >4000 m^2. Participants with a restrictor-only supply lived in a semi-urban environment with 15 participants living on <4000 m^2, 26 participants living on 0.4 to 4 hectares, and nine participants living on >4 hectares. For statistical analysis, two categories of land size were formed: <4000 m^2 and >4000 m^2. Participants with a metered supply lived on a smaller land area than participants with a restrictor-only water supply ($\chi^2 = 45.943$, $p<0.0005$).

Figure 9 shows the number of people that lived at each dwelling. A Mann-Whitney test showed that the number of people that lived at each dwelling was the same across category types for participants with a metered and a restrictor-only water supply ($p=0.976$).

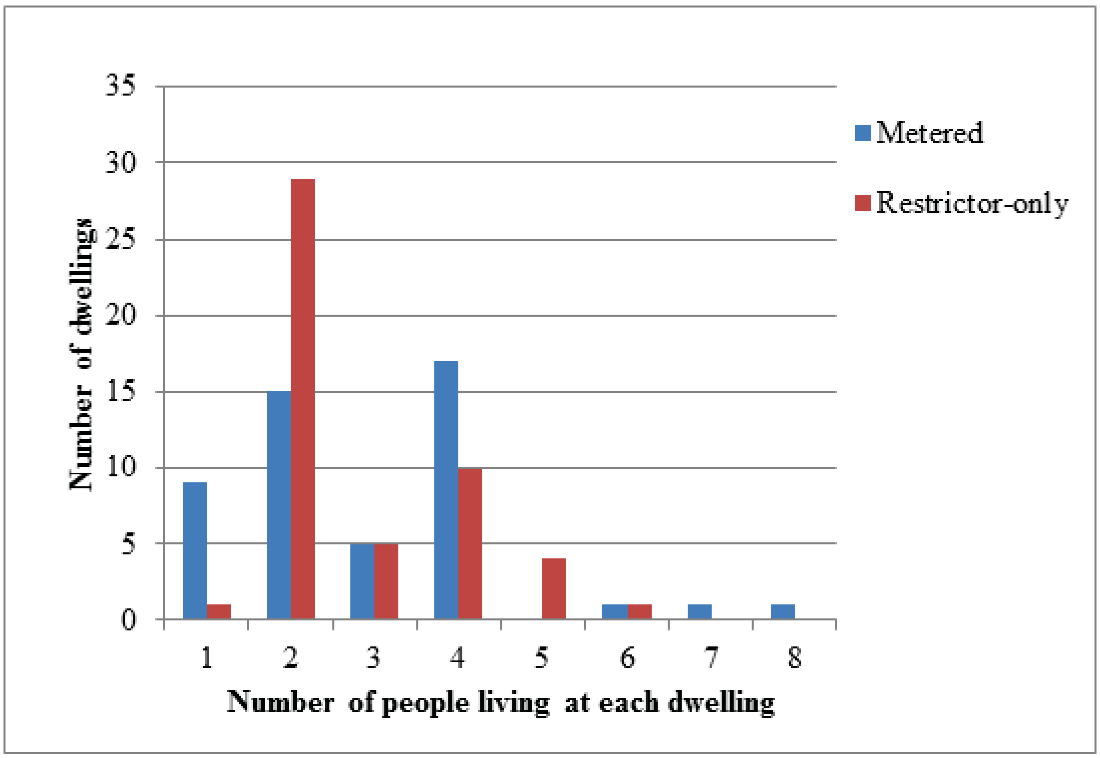

Figure 9. Number of people living at each dwelling with a metered or a restrictor-only water supply

Number of bedrooms per dwellings is shown in Figure 10. Just over half (51%) of all participants with a metered supply had three bedroomed dwellings and more than half (54%) of all participants with a restrictor-only supply had four bedroomed dwellings. A Mann-Whitney test was performed and the number of bedrooms for metered and for restrictor-only dwellings was found to not be the same for each dwelling type ($p<0.0005$). Dwellings with a restrictor-only supply had more bedrooms than dwellings with a metered supply.

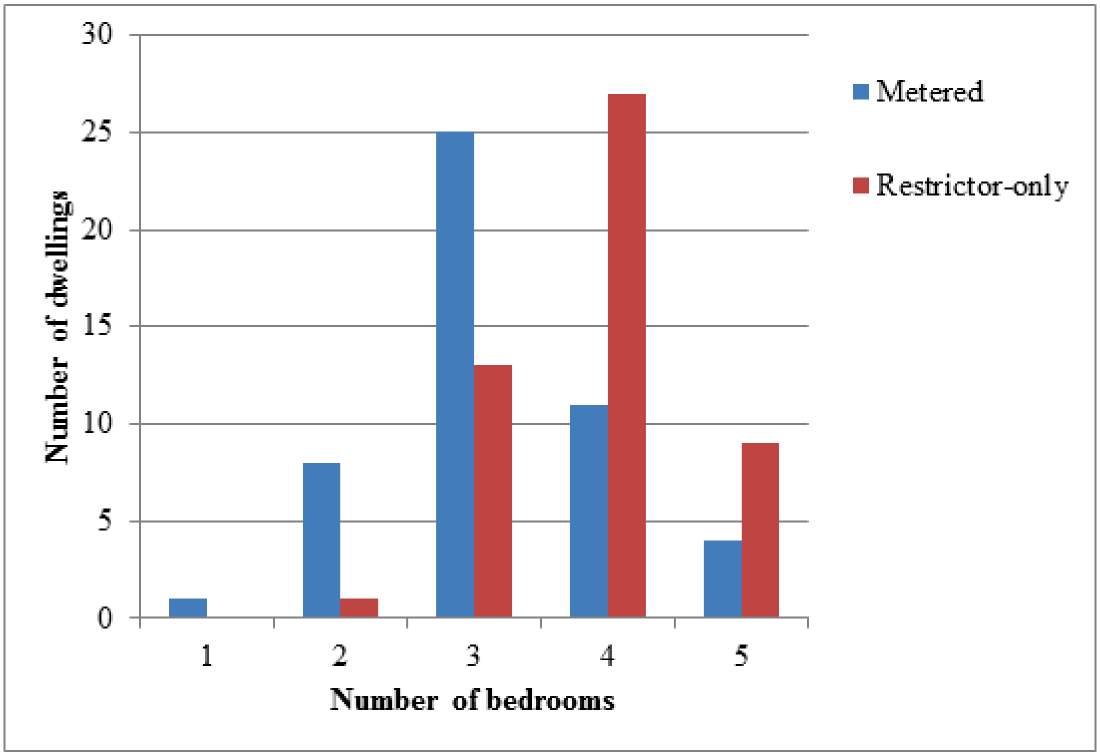

Figure 10. Number of bedrooms for dwellings with a metered or a restrictor-only water supply

7.3 Water usage

All participants with a metered supply said that they, or members of their family, prepared food, mixed drinks, brushed teeth, and drank the water from their household kitchen tap. All participants with a restrictor-only supply said that they prepared food and brushed teeth with the water from their kitchen tap. Two participants with a restrictor-only supply said that they only drank the water from their bench-top filter tap. The other 48 participants with a metered supply all drank the water and mixed drinks with the water from their kitchen tap. Not all participants made ice with the water from their kitchen tap: 11 out of 50 participants with a metered supply and five out of 50 participants with a restrictor-only supply said that they either did not make ice or they made ice with an ice-making unit in their freezer.

7.4 Microbiological water test results

7.4.1 Total coliform results

The total coliform results for metered and restrictor-only dwellings, grouped into three categories, are shown in Figure 11. For metered dwellings, counts for total coliforms ranged from <1 up to 4.1 total coliforms per 100 ml with a median value of <1 total coliform per 100 ml. For restrictor-only dwellings, counts for total coliforms ranged from <1 up to 344.8 total coliforms per 100 ml with a median of one total coliform per 100 ml.

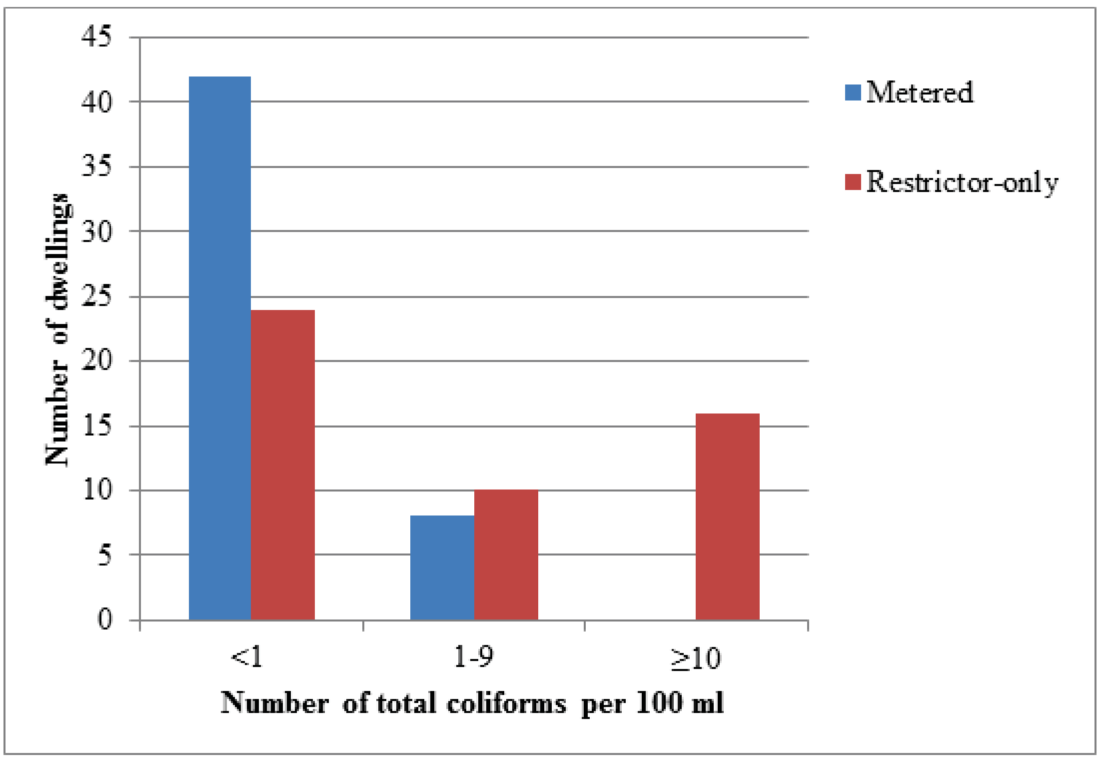

Figure 11. Number of total coliforms per 100 ml for dwellings with a metered or a restrictor-only water supply

For statistical analysis total coliform counts recorded were grouped into three groups: <1; 1-9; and ≥10 total coliforms per 100 ml. The hypothesis that microbiological quality of drinking-water at the kitchen tap was the same for dwellings with an on-demand, metered supply compared to dwellings with a restricted, low-flow supply, was rejected when using total coliforms as a measure of microbiological drinking-water quality (χ^2= 21.131, p <0.0005). More dwellings with a restrictor-only supply had total coliforms in their drinking-water than dwellings with a metered supply.

7.4.2 *E.coli* results

The *E.coli* counts for metered and restrictor-only dwellings, grouped into three categories, are shown in Figure 12. For metered dwellings, all *E.coli* counts were <1 *E.coli* per 100 ml. For restrictor-only dwellings, counts ranged from <1 to 4.1 *E.coli* per 100 ml, with a median of <1 *E.coli* per 100 ml.

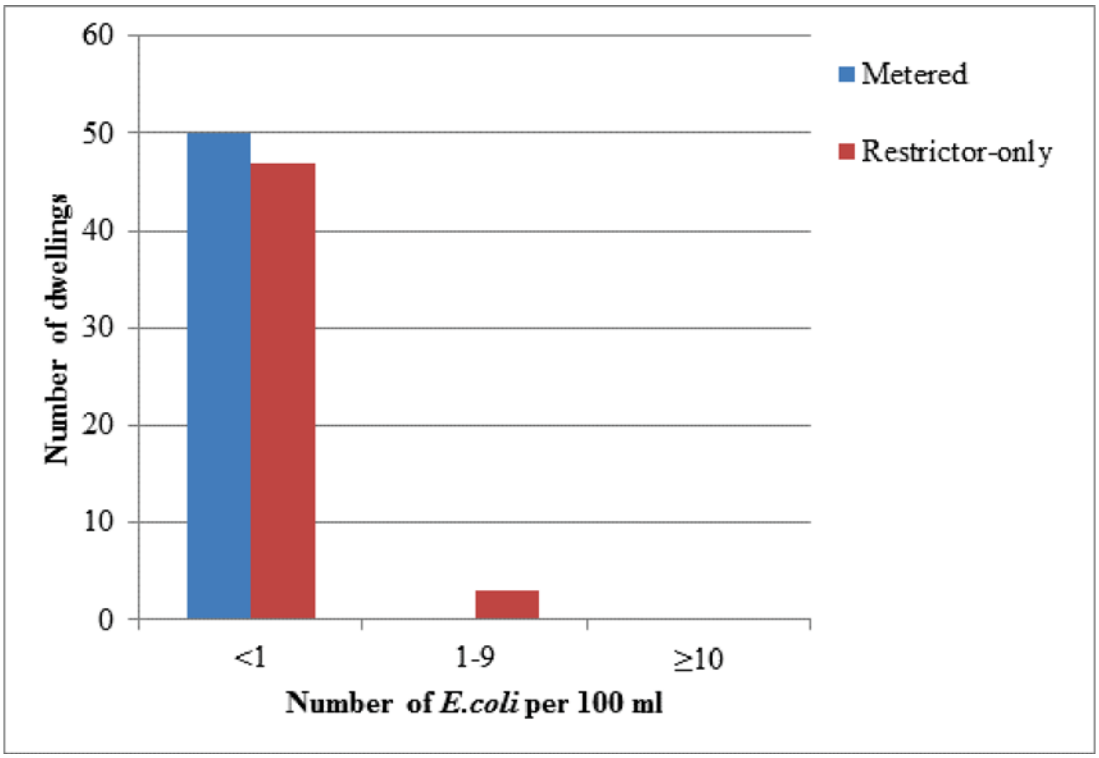

Figure 12. Number of *E.coli* per 100 ml for dwellings with a metered or a restrictor-only water supply

The results from the Fisher's exact test showed that the hypothesis, stating that microbiological quality of drinking-water at the kitchen tap was the same for dwellings with an on-demand, metered supply compared to dwellings with a restricted, low-flow supply, was not rejected when using *E.coli* as a measure of microbiological drinking-water quality (p=0.242). Dwellings with a metered supply had the same microbiological water quality as dwellings with a restrictor-only supply. Two cells had a count of less than five.

7.4.3 Compliance with the DWSNZ 2005 (Revised 2008)

The results for compliance with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) are shown in Table 3.

Table 3. Number of metered and restrictor-only dwellings compliant with microbiological criteria set in the DWSNZ 2005 (Revised 2008)

Dwelling type	Total coliform compliance		*E.coli* compliance	
	Yes	No	Yes	No
Metered	42	8	50	0
Restrictor-only	24	26	47	3

Total coliform compliance

If total coliforms were used as an indicator of contamination then 84% (42/50) of metered dwellings and 48% (24/50) of restrictor-only dwellings complied with the total coliform standard of <1 total coliform per 100 ml set in the DWSNZ 2005 (Revised 2008) (MoH, 2008). The chi squared statistic showed there to be a significant difference in compliance rates between metered and restrictor-only dwellings (χ^2=14.439, $p<0.0005$) when total coliforms were used as an indicator organism. There were more metered dwellings compliant with the Standards than restrictor-only dwellings.

***E.coli* compliance**

The results in Table 3 show that all of the metered, urban dwellings sampled and 94% (47/50) of the restrictor-only dwellings complied with the *E.coli* criteria of <1 *E.coli* per 100 ml set in the DWSNZ 2005 (Revised 2008) (MoH, 2008). Statistical analysis showed that there was not a significant difference in compliance rates between the number of metered and restrictor-only dwellings when *E.coli* was used as an indicator organism ($p=0.242$).

7.5 Water treatment devices

7.5.1 Number and type of water treatment devices utilised

There were 14 participants that utilised water treatment devices for their drinking-water supply: five of these participants had a metered supply and nine had a restrictor-only supply. Table 4 provides details of the type of treatment device utilised by these participants.

Table 4. Type of water treatment devices installed by participants

Dwelling type	Under-bench fine filtration[ab]	Under-bench; filtration size unknown[b]	H_2O_2	Chlorination	UV system
Metered	1	4	0	0	0
Restrictor-only[c]	3	3	2	2	0

[a]Actual filtration size could not be ascertained but participants believed there filter to be a 'fine filtration' system of < 10 microns

[b] filter taps were stand-alone taps that were separate to the main kitchen water tap. The filtration unit was situated under the bench.

[c]one household had undertaken two types of water treatment; chlorination and fine filtration

Four participants with restrictor-only supplies had utilised water treatment devices that supplied treated water to the whole house: two participants had treated their tanks with hydrogen peroxide and two with chlorine. Eleven dwellings with water treatment devices had a filter tap in the kitchen that provided a source of treated drinking-water. Although participants had a filter tap installed they said that water was still consumed from the non-filtered taps in the house by some or all of the members of their household.

7.5.2 Reasons given for installation of water treatment devices

Of the five dwellings with a metered supply and a water treatment system, one participant had installed their fine filtration system to ensure that drinking-water was ‘safe’ to drink. The other four participants stated that the filtration system had been present in the house when they moved in (Table 5).

For restrictor-only dwellings with a water treatment device, three dwellings had been purchased with the filtration system already in place. Five participants said that they had installed a water treatment device to ensure that the drinking-water supply was ‘safe’ to drink and free of harmful micro-organisms. Of these five, three believed that they had contracted gastrointestinal illness from drinking their household water supply. One participant had installed a filtration system to ensure that ‘all nasty chemicals, in particular all the chlorine, were removed from the water’.

7.5.3 Effectiveness of water treatment devices

The results of the water testing of dwellings with water treatment devices are shown in Table 5. When a stand-alone filtration system has been used, results shown are for drinking-water from the kitchen tap (untreated water from the Richmond supply) and drinking-water from the filter tap (home-treated water from the Richmond supply).

Table 5. Maintenance undertaken and effectiveness of water treatment devices installed

			Total coliforms/100 ml		*E.coli*/100 ml			
ID	**Dwelling supply type**	**Type of treatment**	**Untreated**	**Treated**	**Untreated**	**Treated**	**Reason for installation**	**Maintenance**
M5	Metered	Under-bench fine filtration	<1	<1	<1	<1	To ensure water is microbiologically safe to drink.	Annually by service technician
M8	Metered	Under-bench[a]	<1	<1	<1	<1	Installed by previous owners	None
M10	Metered	Under-bench[a]	<1	<1	<1	<1	Installed by previous owners	Annually by participant
M36	Metered	Under-bench[a]	<1	<1	<1	<1	Installed by previous owners	Annually by participant
M48	Metered	Under-bench[a]	<1	<1	<1	<1	Installed by previous owners	None
R1	Restrictor-only	H_2O_2	N/A[b]	<1	N/A[b]	<1	To ensure water is microbiologically safe to drink.	Once, by participant
R7	Restrictor-only	Under-bench[a]	<1	<1	<1	<1	Installed by previous owners	None

			Total coliforms/100 ml		*E.coli*/100 ml			
ID	**Dwelling supply type**	**Type of treatment**	**Untreated**	**Treated**	**Untreated**	**Treated**	**Reason for installation**	**Maintenance**
R30	Restrictor-only	Chlorination; under-bench fine filtration	7.4	<1	<1	<1	To ensure water is microbiologically safe to drink.	Annually by participant. Chlorination by TDC
R31	Restrictor-only	Chlorination	N/A[b]	66.3	N/A[b]	<1	To ensure water is microbiologically safe to drink.	Once, by TDC
R32	Restrictor-only	Under-bench fine filtration	32.7	19.9	<1	<1	To ensure water is microbiologically safe to drink.	Annually by participant
R39	Restrictor-only	Under-bench[a]	5.2	<1	<1	<1	Installed by previous owners	None
R46	Restrictor-only	Under-bench fine filtration	18.3	6.2	<1	<1	To remove chlorine from water supply	Annually by service technician
R52	Restrictor-only	H_2O_2	N/A[b]	98.7	N/A[b]	<1	To ensure water is microbiologically safe to drink.	Once, by participant
R56	Restrictor-only	Under-bench[a]	344.8	26.9	<1	<1	Installed by previous owners	None

[a] bench top filter but participant did not know type or size of filter used

[b] information not available as supply for whole house was treated

Figure 13 shows the effectiveness of the fine filtration system fitted at dwelling R30. When there was no filtration present, tap water was found to have 7.4 coliforms per 100 ml (seven wells positive for total coliforms). After fine filtration, there was <1 coliform per 100 ml (no wells were positive for total coliforms).

R30: Tap water, no filtration R30: Tap water with filtration

Figure 13. Microbiological results for dwelling R30 showing the effectiveness of the filtration system fitted at this dwelling

7.6 Water testing behaviour

No participants with a metered supply had ever had their drinking-water tested and 14% (7/50) of participants with a restrictor-only supply had had their drinking-water tested.

7.6.1 Reasons for having water tested

All seven of the participants who had had their drinking-water supply tested did so to determine if their drinking-water supply was microbiologically safe to drink (Table 6). Four of these seven participants had either been sick with diarrhoea or had had family members that were sick with diarrhoea.

Table 6. Previous water testing results and current water test results for participants who have had their water tested previously

Previous testing behaviour and results						Current test results at kitchen tap	
ID	**Tested for**	**How often tested**	**Result**	**Why tested**	**Treatment since testing**	**Total coliforms per 100 ml**	***E.coli* per 100 ml**
R1	*E.coli* and total coliforms	Once, 12 years ago	No contamination	Moving into house and wanted to test if water was safe to drink.	H_2O_2 into storage tank six months ago	<1	<1
R30	*E.coli* and total coliforms	Twice, 2 years ago	*E.coli* present	Sickness/diarrhoea in family. Council tested water and it showed positive for *E.coli*. Chlorinated tank and re-tested to show no contamination	Chlorination of tank. Installed fine filtration system to remove all microorganisms	7.4 <1[a]	<1 <1[a]
R31	*E.coli* and total coliforms	Twice, 2 years ago	*E.coli* present	Sickness/diarrhoea in family. Council tested water and it showed positive for *E.coli*. Chlorinated tank and re-tested to show no contamination	Chlorination of tank two years ago; no further treatment	66.3	<1

Previous testing behaviour and results						Current test results at kitchen tap	
ID	**Tested for**	**How often tested**	**Result**	**Why tested**	**Treatment since testing**	**Total coliforms per 100 ml**	***E.coli* per 100 ml**
R36	*E.coli* and total coliforms	Once, 2 years ago	No contamination	Neighbours on same supply were sick. Council tested water to determine if safe to drink	None	<1	<1
R49	*E.coli* and total coliforms	Once, don't know when	No contamination	When they were on creek water; tested to see water was safe to drink.	None	157.6	4.1
R52	*E.coli* and total coliforms	Once, 8 years ago	*E.coli* present	Sickness in family. Three out of four members had diarrhoea.	H_2O_2 into storage tank eight years ago. Installed a new tank.	98.7	<1
R55	Don't know	Once, don't know when	No contamination	Participant was sick. Tested to see if drinking-water was contaminated.	No	24.3	<1

[a] results for filtered water

Five participants had had their water tested once and two participants had had their water tested twice. The two participants that had had their water tested twice were neighbours who had become sick with diarrhoea and believed that their drinking-water supply might be the cause of the illness. They contacted the Tasman District Council who checked their water supply and found it to be contaminated with *E.coli* and coliforms. Investigations by the Council determined that a water stock trough had been connected to a shared water storage tank in such a way that water from the trough was back-feeding into the storage tank. After the trough connection had been removed, the storage tanks were chlorinated. Subsequent testing by the Council showed the household water supply to no longer be contaminated (G. Bullock, personal communication, March 26, 2012).

7.6.2 Reasons for not having water tested

The reasons given by participants for not having their drinking-water tested are given in Figure 14.

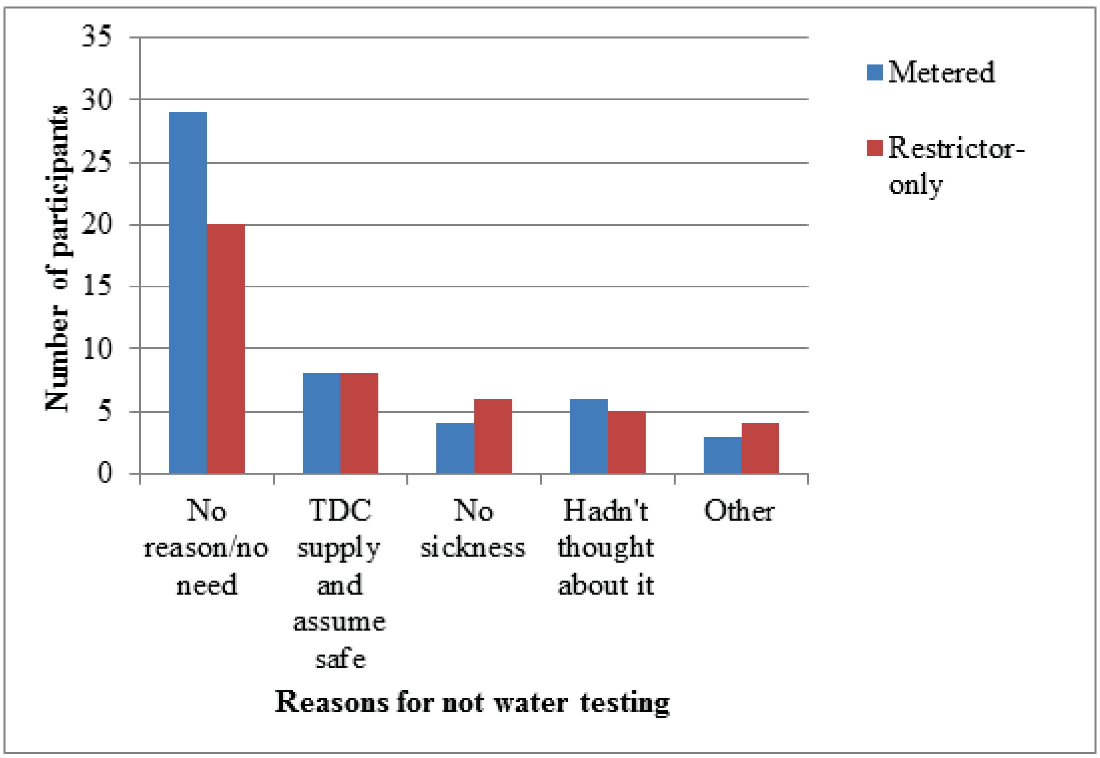

Figure 14. Reasons given by participants with a metered or a restrictor-only water supply for not having their water tested

'Other' reasons given for not performing water testing included that the participant had 'only just moved in', that they had 'meant to but hadn't got around to it', or that they were 'having it done for free now'. Three categories were formed for statistical analysis: 'no need/no reason' and 'no sickness'; 'TDC supply and assume safe'; 'hadn't thought about it' and 'other'. There was no significant difference in the reasons given by participants with a metered supply compared to participants with a restrictor-only supply for not having had their water tested (χ^2= 0.862, p =0.650).

7.7 Perceptions of quality of drinking-water

7.7.1 Perception of taste

The graph in Figure 15 shows participants' perceptions of the taste of their drinking-water supply. In total, 82% of participants with a metered supply and 86% of participants with a restrictor-only supply perceived their drinking-water supply to be of above average quality.

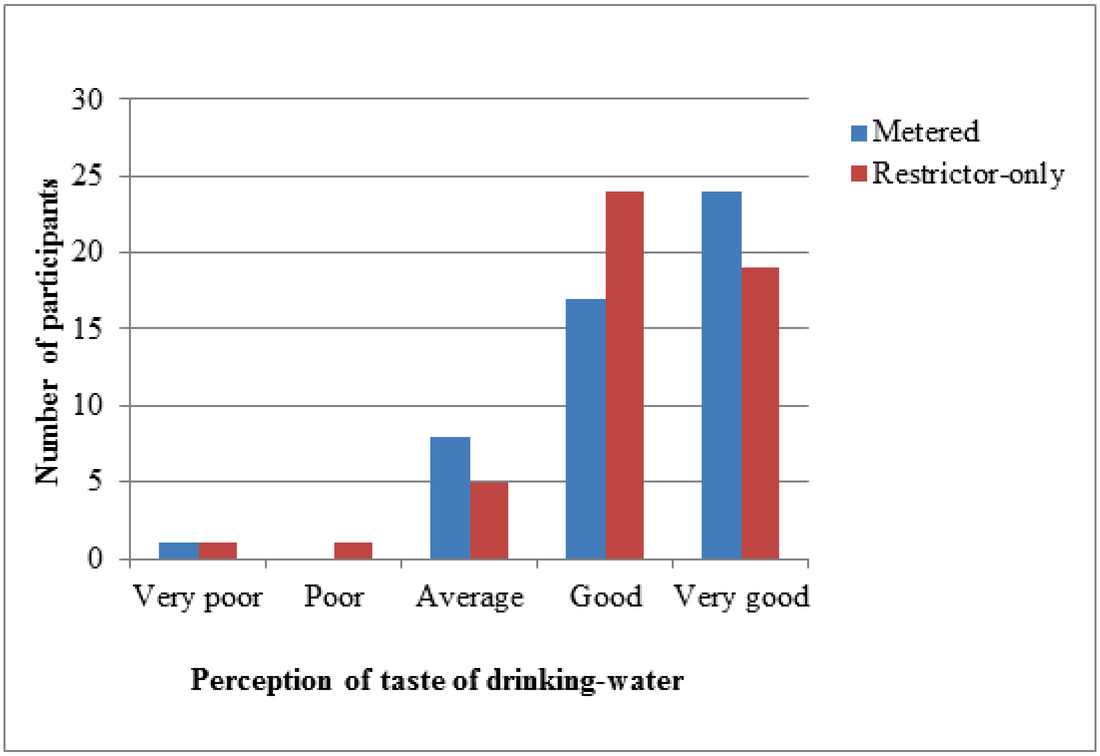

Figure 15. Perception of taste of drinking-water for participants with a metered or a restrictor-only water supply

For statistical analysis, the five response categories have been condensed into three categories: very poor, poor and average; good; and very good. The result of the chi squared test performed on these three categories showed there was no significant difference in perception of taste between participants with a metered supply and participants with a restrictor-only supply (χ^2= 2.027, p=0.363).

7.7.2 Perception of odour

The graph in Figure 16 shows participants' perceptions of the odour of their drinking-water. Perception of odour was rated from very poor to very good with very poor being water with a strong odour that participants did not like and very good being water with no odour at all. In total, 82% of participants with a metered water supply and 88% of participants with a restrictor-only supply rated their drinking-water odour as being of above average quality.

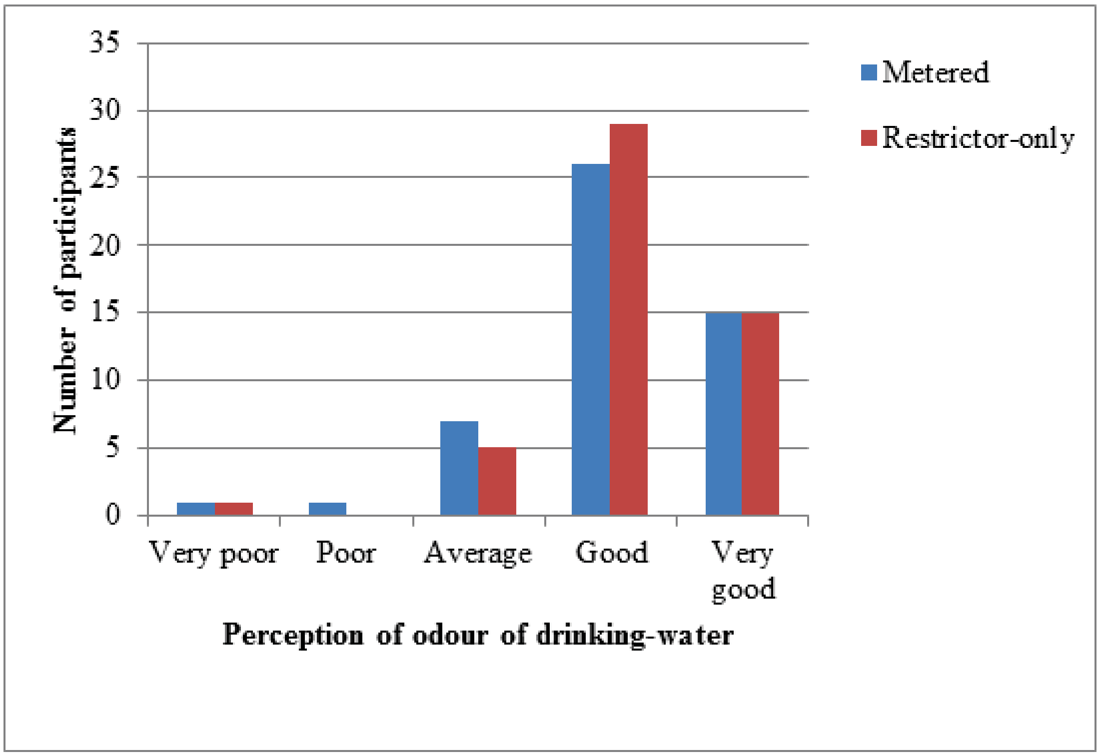

Figure 16. Perception of odour of drinking-water for participants with a metered or a restrictor-only water supply

For statistical analysis, the five response categories have been condensed into three categories: very poor, poor and average; good; and very good. The result of the chi squared test performed on these three groups showed there was no significant difference in perception of odour of drinking-water between participants with a metered supply and participants with a restrictor-only supply (χ^2= 0.764, p=0.683).

7.7.3 Perception of colour

Participants' perception of the colour of their drinking-water is shown in Figure 17. In total, 88% of participants with a metered supply and 94% of participants with a restrictor-only supply perceived the colour of their water to be of above average quality. For statistical analysis two categories were formed: very poor, poor, average and good; very good. There was no significant difference in perception of colour between participants with a metered supply and participants with a restrictor-only supply (χ^2= 0.044, p=0.834).

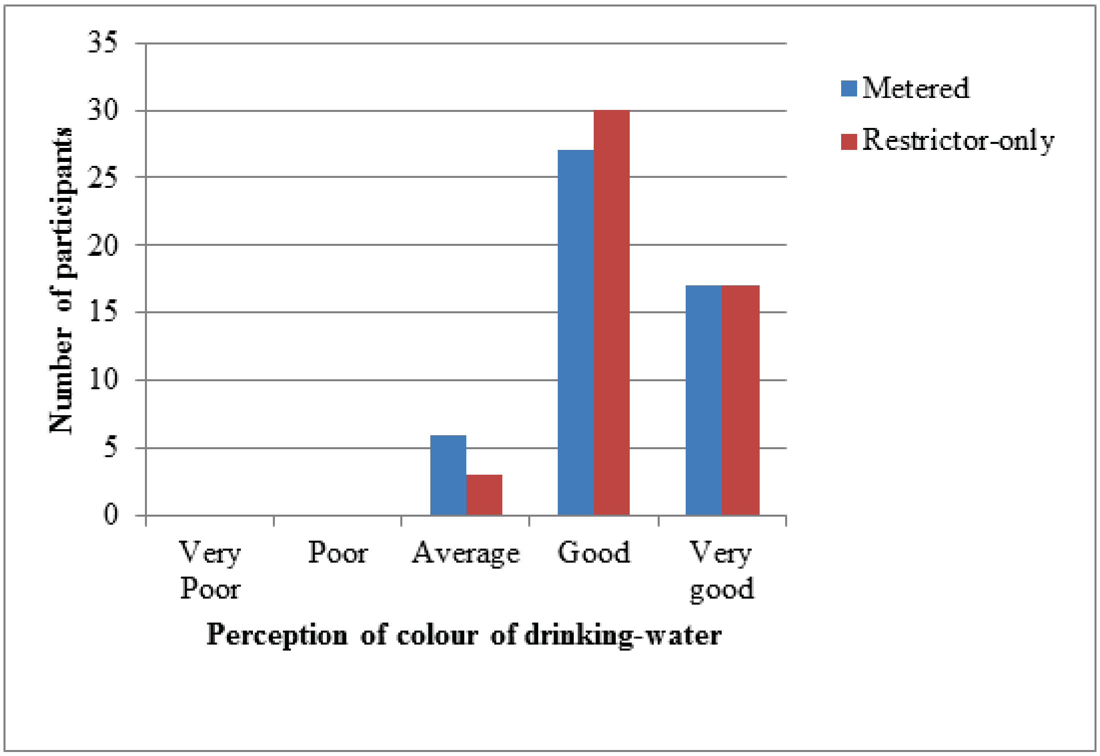

Figure 17. Perception of colour of drinking-water for participants with a metered or a restrictor-only water supply

7.7.4 Perception of safety

Participants' perceptions of the safety of their drinking-water supply are shown in Figure 18. In total, 88% of participants with a metered supply and 82% of participants with a restrictor-only supply perceived their water to be of above average safety. Two categories were formed for statistical analysis: very poor, poor, average and good; and very good. There was no significant difference in perception of safety between participants with a metered supply and participants with a restrictor-only supply ($\chi^2 = 0.015$, p=0.902).

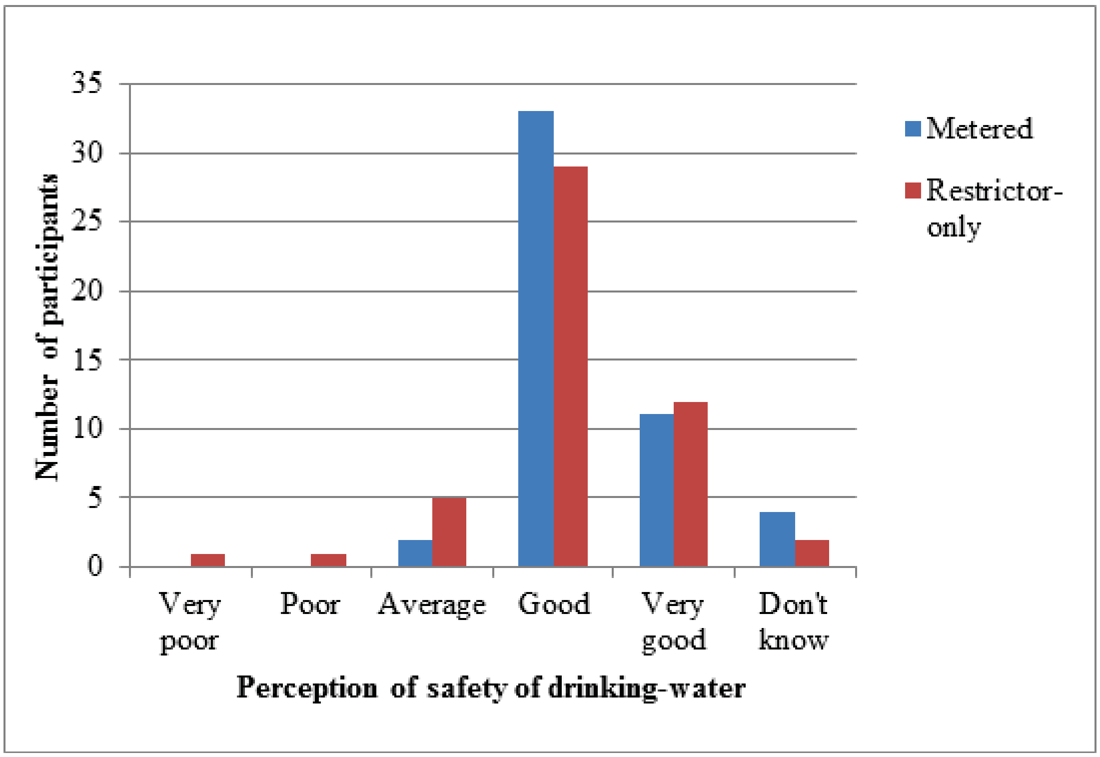

Figure 18. Perception of safety of drinking-water for participants with a metered or a restrictor-only water supply

7.7.5 Perception of value for money

Participants' perceptions of the value for money of their drinking-water supply are shown in Figure 19. In total, 44% of participants with a metered supply and 52% of participants with a restrictor-only supply perceived their water to be of above average value for money. Four categories were formed for statistical analysis: very poor; poor; average; good and very good. There was no significant difference in the perception of value for money between participants with a metered supply compared to participants with a restrictor-only supply (χ^2= 1.204, p=0.752).

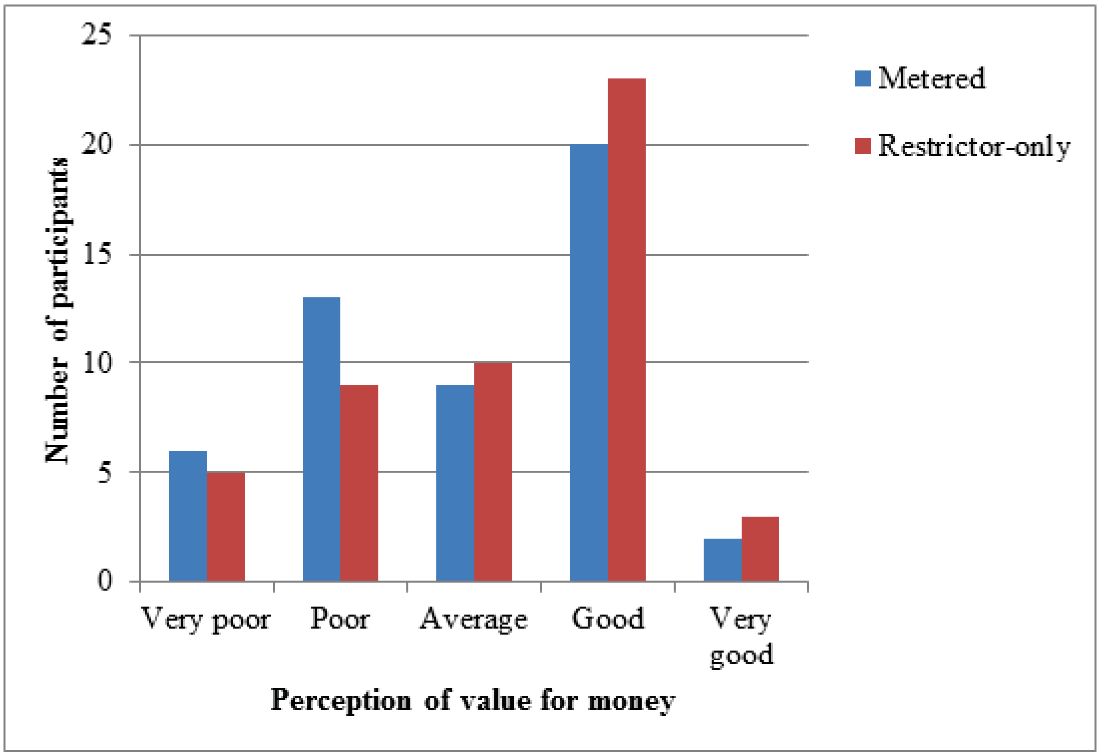

Figure 19. Perception of value for money of drinking-water for participants with a metered or a restrictor-only water supply

7.8 Knowledge of the Richmond urban water supply

7.8.1 Knowledge of treatment status

The results showing participants' knowledge of the treatment status of the Richmond urban water supply are shown in Figure 20. These results show that 10% of all participants knew that the supply was an untreated supply. More participants with a restrictor-only supply (26) compared to a metered supply (19) believed the supply to be treated.

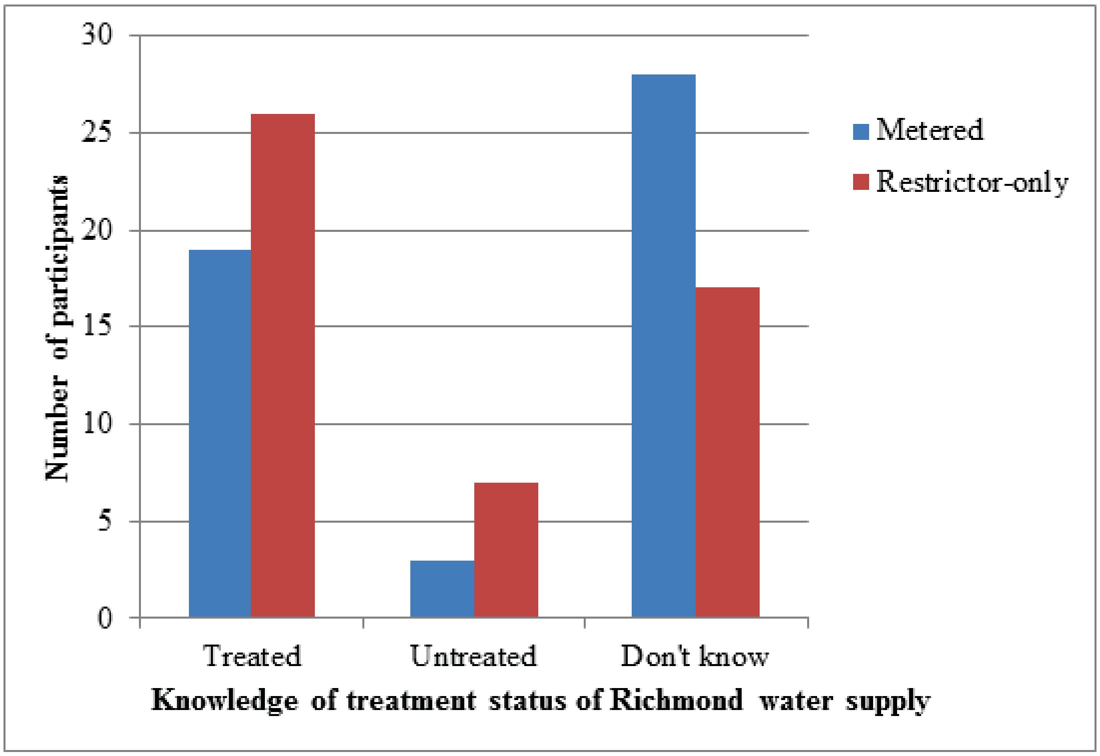

Figure 20. Participants' knowledge of the treatment status of the Richmond water supply

7.8.2 Knowledge of public health grading

The results for participants' knowledge of the health grading of the Richmond urban water supply are shown in Table 7. Most participants with metered dwellings (96%) and with restrictor-only dwellings (94%) did not know the public health grading for the Richmond water supply.

Table 7. Participants' knowledge of the Richmond supply grading

	Knowledge of health grading	
Dwelling type	**Yes**	**No**
Metered	2	48
Restrictor-only	3	47

7.8.3 Access to information sources

The Tasman District Council was the only information source that had been accessed: four participants with a metered supply and 10 participants with a restrictor-only supply had accessed this information source.

7.9 Water storage systems

No participants with a metered dwelling had any type of private water storage system as they did not supplement their drinking-water supply with water from another source. All of the restrictor-only dwellings had a water storage system. Of the 50 participants with restrictor-only supplies; 31 had set-up their own water storage system and 19 stated that their water storage system had been set up by the previous owner of the dwelling.

7.9.1 Number and type of tanks

The 50 restrictor-only dwellings surveyed had a total of 62 water storage tanks between them. The graph in Figure 21 shows the number of water tanks for each dwelling with a restrictor-only supply.

Two groups were formed prior to performing a Fisher's exact test: one tank per dwelling and more than one tank per dwelling. When using total coliforms as an indicator of contamination, levels of compliance with the microbiological criteria stated in the DWSNZ 2005 (Revised 2008) were the same for dwellings with one water tank compared to dwellings with more than one storage tank ($p=0.467$).

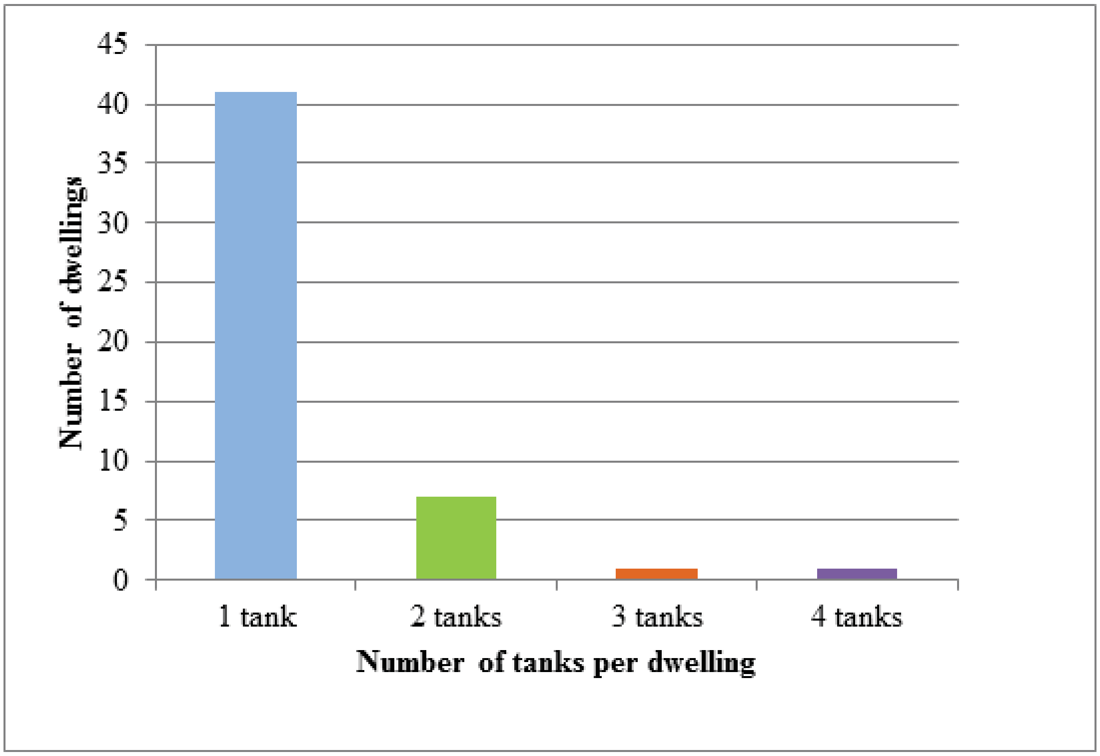

Figure 21. Number of water tanks per dwelling for dwellings with a restrictor-only water supply

Of the 62 tanks, 30 were concrete, 31 polyethylene, and one was fibreglass. For owners of dwellings with only one water storage tank, compliance with the microbiological criteria in the DWSNZ 2005 (Revised 2008) was found to not be the same for dwellings with concrete tanks compared to dwellings with polyethylene tanks (p=0.007). More dwellings with concrete tanks were found to not comply with the Standards compared to dwellings with polyethylene tanks (Table 8).

Table 8. Total coliform counts for polyethylene and concrete water storage tanks for dwellings with one water storage tank

	Total coliforms per 100 ml		
	<1	**>1**	**Total**
Concrete tank	7	14	21
Polyethylene tank	15	5	20
Total	22	19	41

7.9.2 Tank size

Size of tanks varied from 1,000 L up to 30,000 L (Figure 22). Statistical analysis was only undertaken on dwellings with one storage tank. Tank sizes were put into two groups before performing a Fisher's exact test: <20,000 L and ≥20,000 L. For owners of restrictor-only supplies with one water storage tank there was no significant difference in levels of total coliform compliance with the DWSNZ 2005 (Revised 2008) between water storage tanks that were <20,000 L and those ≥20,000 L ($p=1.000$).

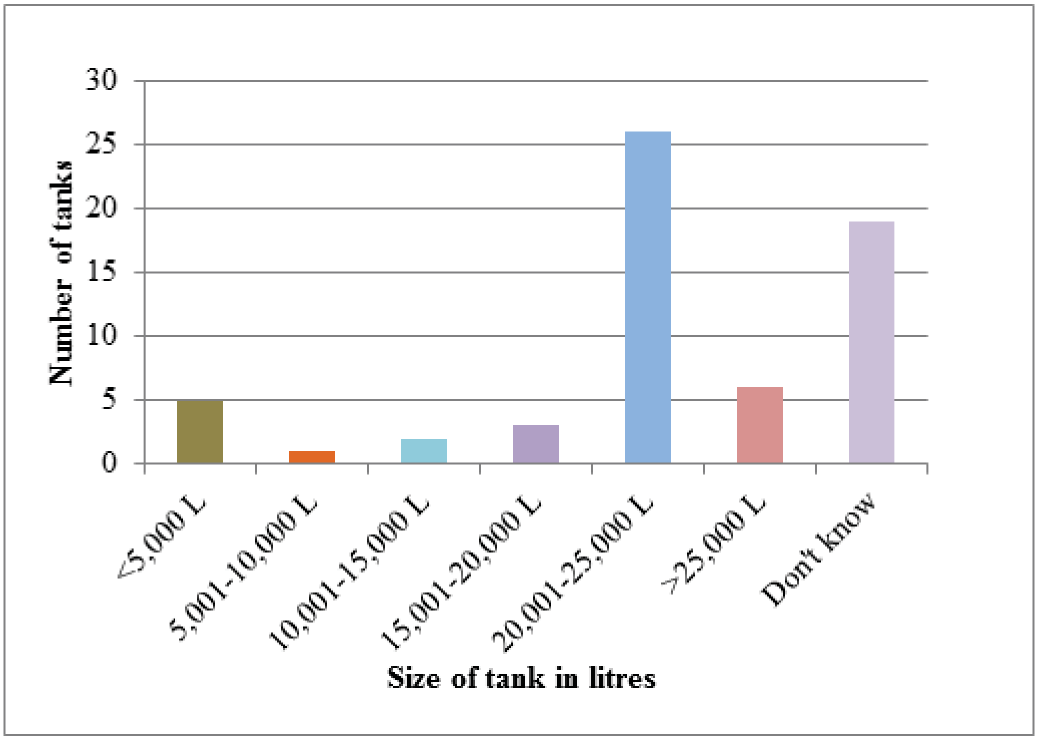

Figure 22. Tank sizes for all water storage tanks owned by participants with a restrictor-only water supply

Total water storage capacity varied with most dwellings (31/50) having a total water storage capacity of 20,000 L or more. Seven dwellings had a total water storage capacity of <20,000 L and 12 participants did not know what total capacity of water they had stored.

7.9.3 Tank age

Age of water tanks is shown in Figure 23. Over half of the water storage tanks (56.5%) were >10 years old. Tank ages were put into two groups before performing a chi squared analysis: tanks <10 years old and tanks >10 years old. For owners of a restrictor-only supply with one water storage tank, there was no significant difference in levels of compliance with the DWSNZ 2005 (Revised 2008) for tanks that were >10 years old compared to tanks that were >10 years old (p=0.204).

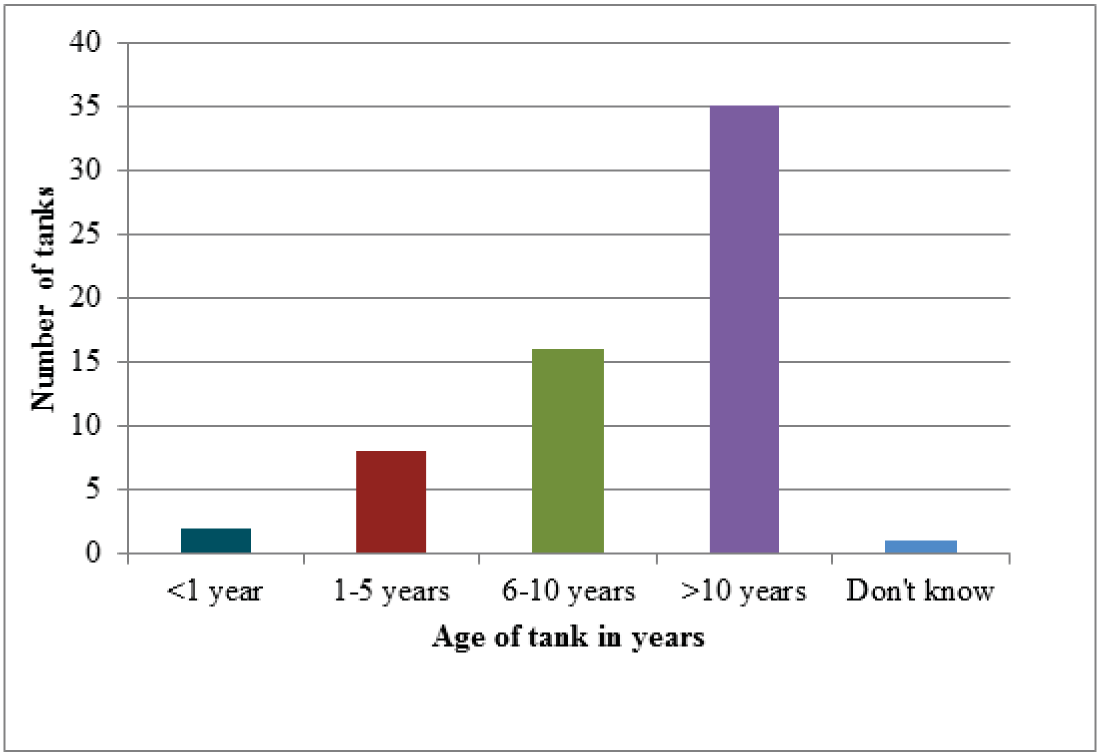

Figure 23. Age of all water storage tanks for dwellings with a restrictor-only water supply

7.9.4 Location of water storage tanks

Of the 62 water storage tanks, 54 were located at ground level, seven below ground, and one was raised above ground. All seven tanks that were below ground were concrete water storage tanks. The tank raised above ground was a concrete tank. Of the seven tanks located below ground, six did not comply with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 total coliform per 100 ml. Of the 54 tanks situated at ground level, 26 complied and 28 tanks did not comply with the microbiological criteria set in the DWSNZ 2005 (Revised 2008). The tank raised above ground did comply with the microbiological criteria stated in the Standards.

7.9.5 Tank accessories

All 62 tanks had a tank inspection opening. Participants with 60 of these tanks knew that the tank lids were firmly. The participants with the other two tanks were unsure if the lids of these tanks were in place. Of the 62 tanks, two had water depth indicators, two had air vents, two had a floating hose draw off and one had a Tasman District Council maintained tank inlet screen. None of the tanks had a tank vacuum system, tank sock, or calmed inlet pipe.

7.10 Frequency of maintenance of water treatment systems

7.10.1 Frequency of maintenance of household water treatment devices

Table 5 provides a summary of the maintenance undertaken on household water treatment devices.

7.10.2 Frequency of tank inspection

The frequency of tank inspection by participants is shown in Figure 24. The five tanks that were inspected monthly were owned by two participants. Both these participants had had water supply problems in the past so regularly checked their tanks to ensure that they had sufficient water in them.

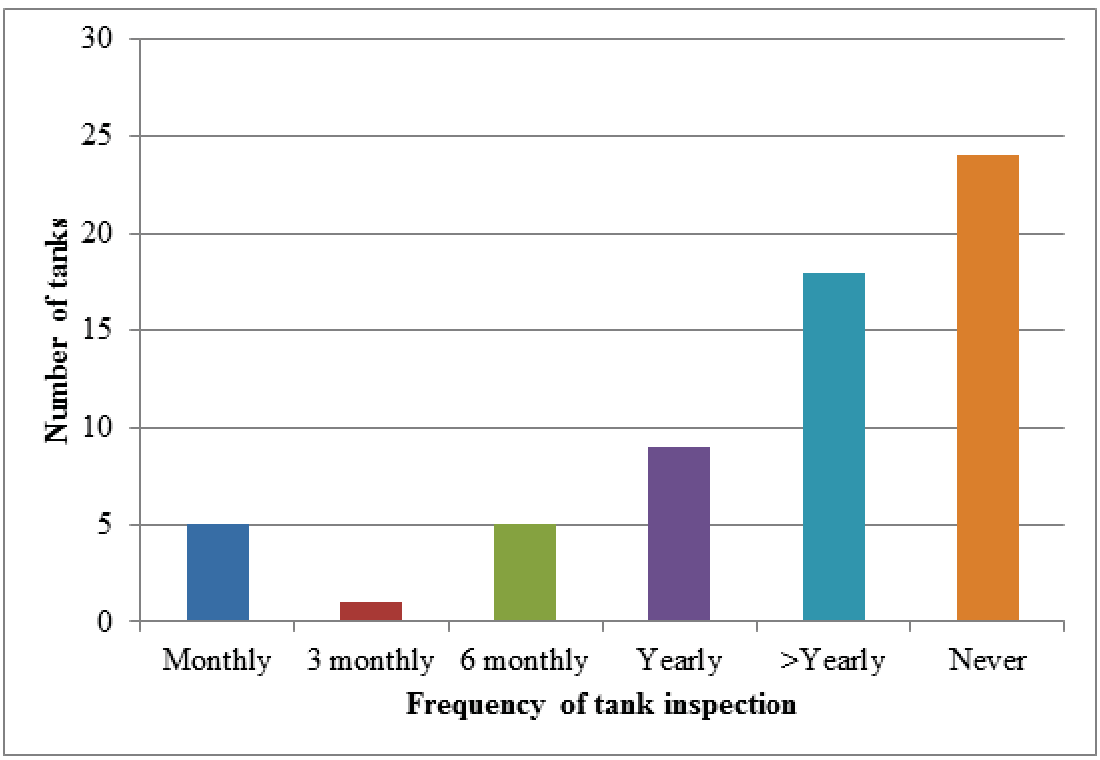

Figure 24. Frequency of inspection of water storage tanks owned by participants with a restrictor-only water supply

7.10.3 Frequency of tank cleaning

Tank cleaning was carried out annually by one participant. This participant drains his plastic tank once a year and then re-fills it. One other participant cleaned their tank on a bi-annual basis. This participant had had a contaminated supply and now cleans out his concrete tank every couple of years. A further two participants had cleaned their tanks once since living at their properties. One of these participants cleaned out their concrete tank when they switched from spring water to Richmond supply. The other participant had a leaking concrete water tank and had the tank drained and re-sealed by a service technician. The remaining 46 participants had never cleaned their water tanks.

7.11 Restrictor-supplemented supplies

7.11.1 Total coliform and *E.coli* results

The total coliform and *E.coli* results for the restrictor-supplemented dwellings are shown in Table 9. Total coliforms ranged from <1 total coliform per 100 ml up to 1,553.1 coliforms per 100 ml. *E.coli* counts ranged from <1 *E.coli* per 100 ml up to 261.3 *E.coli* per 100 ml.

Table 9. Water quality of restrictor-supplemented dwellings

ID	Type of supplementary supply	Total coliforms per 100 ml	*E.coli* per 100 ml
R20	Restrictor plus rainwater	<1	<1
R24	Restrictor plus rainwater	<1	<1
R37	Restrictor plus rainwater	<1	<1
R34	Restrictor plus rainwater	47.4	<1
R23	Restrictor plus rainwater	60.9	<1
R50	Restrictor plus rainwater	124.6	6.3
R10	Restrictor plus rainwater	524.7	9.6
R42	Restrictor plus rainwater	1413.6	29.2
R54	Restrictor plus rainwater	1553.1	1.0
R14	Restrictor plus spring water	43.4	1.0
R27	Restrictor plus well water	866.4	261.3

7.11.2 Compliance with DWSNZ 2005 (Revised 2008)

The results in Table 9 show that three of the 11 dwellings complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 total coliform per 100 ml. If using *E.coli* as a measure of compliance, instead of total coliforms, then five of the 11 dwellings complied with the microbiological criteria in the DWSNZ 2005 (Revised 2008) of <1 *E.coli* per 100 ml.

Further results for restrictor-supplemented supplies are contained in Appendix L.

8 Discussion

8.1 Water quality

8.1.1 Total coliform results

The hypothesis being tested in this study stated that microbiological water quality should be the same for metered and restrictor-only dwellings. This hypothesis was rejected when total coliforms were used as an indicator of contamination, as the results of the water testing showed that microbiological water quality was not the same for dwellings with a metered supply compared to dwellings with a restrictor-only supply ($p < 0.0005$). More dwellings with a restrictor-only supply (42/50) than dwellings with a metered supply (8/50) had coliforms in their drinking-water.

The exact cause of the positive total coliform results in this study could not be ascertained, but there were numerous ways in which this contamination might have occurred. Total coliforms might have entered the supply network at the drinking-water source. This theory was supported by the fact that routine water testing results for the Richmond supply showed that the source water had been contaminated two times in the previous year: once six months prior to sampling and again whilst this study was being carried out (Gillian Bullock, personal communication, November 26, 2011; J. Cuthbertson, personal communication, March 16, 2012; Murdoch, 2012). The contamination event that occurred during this study might well have been the cause of the positive total coliform results for metered dwellings as 75% of the positive results (6/8) occurred prior to, or within three days of the contaminated well being shut down (Section 2.4.2).

The presence of total coliforms in tap samples might not have been due to the contamination of the source water, as contamination might have entered the supply within the distribution network. Distribution systems can become contaminated as a result of back-flow, mains breaks, cross-connections, or poor maintenance (Besner et al., 2002; Craun & Calderon, 2001; Craun et al., 1997, 2010; Schuster et al., 2005). As there were 14 reported mains breaks in the Richmond supply in 2011 (TDC, 2012d), any of these might have been responsible for allowing coliforms to enter the water distribution network.

Once coliforms are present in a network their survival and growth is dependent on many different factors, such as water temperature, presence of disinfectants, and types of piping materials (LeChevallier, 1990; LeChevallier et al., 1996; Lehtola et al., 2004; Niquette, Servais, & Savoir, 2000). The use of filtration in a water supply and the presence of residual disinfectant have both been shown to reduce biofilm formation in distribution networks (Besner et al., 2002;; Hallam, West, Forster, & Simms, 2001; LeChevallier et al., 1996; LeChevallier, Cawthon, & Lee, 1988). As the Richmond supply was untreated and contained no residual disinfectant (TDC, 2012d) this might have led to increases in coliform re-growth and total coliform counts within the distribution network.

Reticulated supplies can become contaminated in household plumbing systems (Eboigbodin et al., 2008; Lautenschlager et al., 2010; Pepper et al., 2004) and contamination within individual households might have accounted for the fact that only some of the dwellings sampled were contaminated. Several examples of household contamination were given by participants in this study. One participant had had a contaminated water supply due to back-flow from a stock trough. Another participant believed their supply to have been contaminated by frogs present in their water tank and a further participant believed their supply to be contaminated due to a dirty filter fitted on their kitchen tap.

In this study more restrictor-only dwellings were contaminated with total coliforms than metered dwellings ($p<0.0005$). There were many possible reasons why water quality may have been different for the two dwelling types. Consumers with a restrictor supply were, in general, located further from the source waters. This means that their water supply has had to travel further and pass through more kilometres of piping and more storage reservoirs before it reached their dwelling. As the formation of biofilms in piping and the use of storage reservoirs has been associated with increased coliform counts (Kerneis et al., 1995; LeChevallier et al., 1996), the longer length of piping and the increased number of storage reservoirs used to supply restrictor dwellings might have led to an increase in coliform counts at these dwellings.

The greatest difference, though, between restrictor supplies and metered supplies was that restrictor supplies had to pipe their water supply to their properties from the restrictor and store their drinking-water in one or more storage tanks prior to use. It appeared that the use of these individual private water storage systems was the most likely cause of the increased levels of contamination in restrictor supplies as neighbouring dwellings with restrictor supplies, but differing water storage systems, were often found to have totally different levels of contamination in their drinking-water supplies.

Water storage tanks are known to provide a suitable environment in which bacteria can survive and grow (Al-Bahry et al., 2011; Martel et al., 2002; Tokajian & Hashwa, 2004). Tanks can also be a site where contamination can enter a water supply (Lee et al., 2006), as cracks in tanks can lead to the ingress of contaminants (Figure 25). Animals, birds, and environmental contamination can enter through open vent pipes. Although most participants (48/50) stated that the lid of their water storage tank was firmly in place, a visual inspection of the tanks showed that some of the concrete tanks were cracked and had plants growing in under the tank lid.

Figure 25. A cracked concrete water storage tank

Regular maintenance of privately owned piping networks and storage tanks is essential in ensuring water supplied to the dwelling is potable (MoH, 2006c, 2010c). Restrictor-only dwellings might have had higher total coliform counts than metered dwellings, as the results from this study showed that owners of restrictor-only supplies rarely carried out maintenance on their water supplies and tanks were seldom cleaned. This lack of maintenance is not unusual as research has shown that owners of private water supplies, who have to store their water prior to use, seldom carry out maintenance or clean their water storage tanks (Abbott et al., 2006; Baguma et al., 2010; Richardson, et al., 2009; Rutter et al., 2000; Said et al., 2003; Thompson, 2011a; Verrinder & Keleher, 2001).

Improperly set up systems can also lead to contamination entering a water supply and might be another reason why more restrictor-only dwellings had total coliform contamination than metered dwellings (MoH, 2010c). An example of this occurred with two dwellings with a restrictor supply. These two dwellings were supplied with water from a shared storage tank. This tank was also used to supply water to stock troughs on one of the properties. The connection to the stock trough was faulty and water was back-feeding from the trough into the water storage tank and contaminating the water supply.

8.1.2 *E.coli* results

In contrast to the total coliform results, the *E.coli* results from this study support the original hypothesis that water quality was the same for metered dwellings when compared to restrictor-only dwellings, as there was no significant difference in water quality between the two dwelling types (p=0.242). As the DWSNZ 2005 (Revised 2008) recommends the use of *E.coli* as an indicator of faecal contamination, it is the *E.coli* results that should be used in preference to the total coliform results in this study (MoH, 2008). However, the total coliform results should not be ignored as total coliforms can be used as an indicator in place of *E.coli* (MoH, 2008). Total coliforms are also a better indicator than *E.coli* of environmental contamination and of re-growth in a distribution system (WHO, 2003; Yates, 2007).

What the *E.coli* results from this study have shown is that it is possible to provide potable water, via a reticulated supply, to metered dwellings without disinfection. This finding corroborates evidence from other countries, such as Norway and the Netherlands, which also provide potable, reticulated water supplies to consumers without disinfection (Kvitsand & Fiksdal, 2010; van der Koij et al., 1999). In order to supply drinking-water without disinfection water suppliers in these countries have adopted the multiple barrier approach to the supply of drinking-water (Kvitsand & Fiksdal, 2010; van der Koij et al., 1999). In the Netherlands barriers include the provision of a biologically stable drinking-water supply, the use of biostable materials in the distribution network, and the implementation of good engineering and maintenance practices (van der Koij et al., 2009). Barriers employed in the Richmond supply network include the use of a good quality groundwater, routine water testing, good network design, and regular maintenance.

Although none of the metered dwellings had *E.coli* contamination in their drinking-water supplies, three restrictor-only dwellings were found to have low levels of *E.coli* contamination. As there have been no comparable studies with which to compare these results it is difficult to know whether the presence of low *E.coli* counts in these restrictor supplies was to be expected. A study undertaken in Germany, which looked at the results of water testing carried out in public buildings, established that 14 of the 5,496 samples taken were positive for *E.coli*. In regional New South Wales, Australia, where water testing to determine compliance is undertaken at the kitchen tap, a study undertaken by Cretikos et al. (2010) ascertained that 40% (129/323) of all the supply systems in this region did not comply with the *E.coli* standards set in the Australian Drinking Water Guidelines. For these non-compliant supplies, *E.coli* was detected in more than two out of every 100 samples taken.

Although these overseas studies show that reticulated supplies can be contaminated with *E.coli* when they reach the consumers tap (Cretikos et al., 2010, Volker et al., 2010), both overseas studies have marked differences to this study. The German study was undertaken on public buildings owned by different local authorities. No indication was given of the source waters, treatment mechanisms employed, or quality of water in the distribution networks for these buildings (Volker et al., 2010). The Australian study was undertaken on over 300 supplies of varying sizes, with different source waters and treatment mechanisms (Cretikos et al., 2010).

As the Richmond supply had distribution zone compliance and 97% of the dwellings sampled were found to not be contaminated with *E.coli*, it would appear that the *E.coli* present in the drinking-water of the three contaminated dwellings might be related to the water storage systems used by these dwellings. Further investigations revealed this to be the case. One of the three properties, with *E.coli* in their drinking-water, had a contaminated water storage tank. Plants growing around the tank had grown in under the tank lid and formed a 10 cm thick mat of roots in the water tank. The owner of the second dwelling, with a positive *E.coli* count, stated that the water tank had become contaminated whilst repair work was being undertaken on the ballcock. However, this participant also mentioned that snails were present in the tank which implied that the tank was contaminated prior to the maintenance work being carried out. There appeared to be no apparent reason for the *E.coli* contamination at the third dwelling. The water storage tank of this dwelling was less than five years old, it was polyethylene, the tank lid was firmly in place, and there was no evident entry place for contaminants.

8.2 Indicator organisms

There has been extensive debate and numerous articles written on the choice and use of indicator organisms (Edberg et al., 2000; Neumann et al., 2005; Standridge, 2008; Stevens et al., 2003; WHO, 2011; Yates, 2007) and the results from this study highlight some of the issues with the use of these organisms.

- Lack of correlation between the *E.coli* results and the total coliform results (Abbott et al., 2006). The results from this study clearly demonstrate how the use of different indicator organisms can provide differences in the conclusions drawn regarding the safety of a water supply. When using total coliforms, 34% of dwellings were found to have a contaminated water supply compared to 3% of dwellings, when using *E.coli* as an indicator organism.
- Different indicators can be used for different purposes (WHO, 2003; Yates, 2007). *E.coli* results provide an indication of the presence of faecal contamination (Edberg et al., 2000), whereas the total coliform results provide an indication of the presence of environmental contamination or the presence of biofilms in the distribution network (WHO, 2003).
- The use of more than one indicator can provide a clearer picture of the quality of a water supply (WHO, 2003; Yates, 2007). When using *E.coli* as an indicator, the results from this study demonstrated that the water supplied to all metered dwellings and 94% of restrictor-only dwellings was potable and did not contain any faecal contamination. However, the total coliform

results showed that the water supplied to 16% of metered dwellings and 52% of restrictor-only dwellings was not potable and contained environmental contamination.

- The presence of an indicator organism is not necessarily an indication that the water supply is a health hazard and contains pathogenic microorganisms (Craun et al., 1997; Craun, Nwachukwu, Calderon & Craun, 2002; Wu et al., 2011). The presence of *E.coli* in a water supply is an indication that faecal contamination of the supply has occurred, but it does not definitely mean that pathogens are present in the supply. Research has also shown a similar situation for total coliforms, as their presence in a water supply is not always correlated with the presence of pathogens (Ahmed, Vieritz, Goonetilleke, & Gardner, 2010; Wu et al., 2011) or with incidences of gastrointestinal disease (Payment et al., 1993; Risebro, Breton, Aird, Hooper, & Hunter, 2012; Strauss et al., 2001).

8.3 Supplementary supplies

Although there were only 11 participants with restrictor-supplemented supplies the water testing results for these 11 supplies showed that adding water from another source to a reticulated supply might have led to a loss in water quality. Just over 70% of the restrictor-supplemented supplies had total coliforms in their drinking-water compared to 52% of restrictor-only supplies. Furthermore, 54.5% of restrictor-supplemented supplies had *E.coli* in their water supply compared to 6% of restrictor-only supplies. Similar studies to determine the water quality of reticulated supplies, supplemented with a private water source, have not been undertaken. However, studies undertaken to determine the microbiological quality of private water supplies, sourced from a variety of sources, have shown that these supplies are often microbiologically contaminated (Abbott et al., 2006; Hexemer et al., 2008; Kay et al., 2007; Reid et al., 2003; Richardson et al., 2009; Simmons et al., 2001).

Results from this study showed that, not only were more restrictor-supplemented dwellings contaminated with total coliforms, but levels of contamination were higher for these dwellings as well. Total coliform counts per 100 ml for restrictor-supplemented dwellings ranged from <1 up to 1,553.1 and *E.coli* counts per 100 ml ranged from <1 up to 261.3 *E.coli*. The highest total coliform counts for restrictor-supplemented supplies were obtained by participants who supplemented their supply with roof-collected rainwater, whereas the highest *E.coli* count was obtained by the participant who had a well water supplemented drinking-water supply.

High total coliform counts for owners of private water supplies, who source their water from rainwater, are not unusual and are an indication that these supplies were heavily contaminated with environmental contamination (Abbott et al., 2006; Simmons et al., 2001). Heavy rainfall had preceded water sampling and had probably washed any contaminants present on the roof into the water storage tank (Yaziz, Gunting, Sapari, & Ghazali, 1989).

The high total coliform and *E.coli* counts for the participant with well water as a supplementary supply were a surprise as underground water should be of good quality (MoH, 2005c; Schmoll et al., 2006). However, this well was fed by an underground stream which stock had access to. Heavy rain had preceded sampling and was likely to have washed cattle faeces into the water supply.

8.4 Water usage

The consumption patterns of tap water in this study confirmed previous research which showed that the type of water consumed was linked to perceptions of the safety of a water supply and its taste (Doria et al., 2009; Jones et al., 2007; Levallois et al., 1999). In this study 98% of participants drank tap water and 97% of participants rated the taste and 98% rated the safety of their drinking-water as average or above. The two respondents who only drank home-treated water cited ‘health concerns’ as the reason for not consuming tap water. This confirms previous research which has shown that ‘health concerns’ was one of the main reasons why people consume home-treated water instead of tap water (Dupont et al., 2010).

8.5 Water treatment devices

Only 14% of participants in this study had a water treatment system installed at their dwelling. This low percentage contrasts with the results from surveys conducted in Canada which have shown that just over half of respondents treat their water at home prior to consumption (Jones et al., 2007; Pintar et al., 2009; Statistics Canada, 2009). There are two possible reasons why these differences might have occurred. Firstly, the use of home treatment devices may have been lower in this study because participants were happy with the organoleptic properties and safety of their water supply. Participants, therefore, might not have felt the need to install a water treatment device. Secondly, both surveys undertaken in Canada were carried out after a large waterborne outbreak had occurred in Walkerton, Ontario when an estimated 2000 people became ill and seven died (Hrudey et al., 2003). This outbreak might have led to an increased awareness for Canadians of the problems with drinking contaminated water and for the need to install a water treatment device (Dupont et al., 2010; Geldreich, Taylor, Blannon, & Reasoner, 1985). Outbreaks of this size have not occurred in New Zealand and people in this country may not be aware of the problems that can arise when reticulated supplies become contaminated.

The type of water treatment device fitted was also different in this survey compared to previous surveys undertaken overseas (Jones et al., 2006; Pintar et al., 2009; Statistics Canada, 2009). In a survey conducted in Canada, by Pintar et al. (2009), 52% of participants (n=1,326) were found to use a jug filter, 15% used a filter on the tap, but no participants were found to have used chlorination or hydrogen peroxide as a method of water treatment. These results are in contrast to the results from this study which showed that 11% of participants used an under-bench filter; 2% had added chlorine, and a further 2% had added hydrogen peroxide to the water in their storage tanks.

All of the participants who had either fitted an under-bench filtration system or who had shock-dosed their water storage tank had done so to ensure that their water was ‘safe to drink’. These participants either knew of neighbours who believed that they had become sick from their drinking-water supply or they, or members of their family, believed they had contracted gastro-intestinal illness from the consumption of their drinking-water. This finding correlates with other studies which have also shown that health concerns related to the consumption of contaminated water were one of the main reasons why respondents had installed a water treatment device (Dupont et al., 2010; Jones et al., 2006).

Research has shown that under-bench water treatment devices are not always effective at removing microbial contamination and may even, in some instances, act as a source of contamination (Chaidez & Gerba, 2010; Su et al., 2009; Geldreich et al., 1995; Payment, 1989). Five of the under-bench filters fitted in this study reduced total coliforms present but only two of these five filters removed all the total coliforms that were present in the unfiltered water sample. It was unclear why these filters did not remove all the contamination present but was most likely due to the filter being inadequate for the purpose of removing microorganisms. The filters appeared to be for the removal of large rather than microscopic particles. Surprisingly, none of the filters were found to increase levels of contamination even though five participants never carried out any maintenance on their filtration systems.

Two of the four dwellings that had treated their water storage tanks with a shock-dose of either chlorine or hydrogen peroxide still had total coliforms present in their water supply. There are several reasons why total coliforms may be present in these two supplies after treatment. Firstly, treatment may not have been effective. Secondly, the water storage tank may not have been the source of the contamination. Lastly, a one-off dose of chlorine or hydrogen peroxide will only inactivate microbiological contamination present in the tank at the time of treatment and the tank may have become re-contaminated. To ensure continued disinfection of the water supply, a recommended chlorine disinfection residual of 0.2 mg/L would need to be maintained in the tank (MoH, 2008).

8.6 Water testing behaviour

No participants with a metered water supply in this study and only seven participants with a restrictor supply had ever had their water tested. These low rates of water testing behaviour were not a surprise for two reasons. Firstly, previous research involving owners of private water supplies has shown that water testing is seldom undertaken (Jones et al., 2005, 2006). Secondly, participants in this survey were supplied with a reticulated supply of water that had been routinely tested by the Tasman District Council to ensure that the supply gained distribution zone compliance. Further testing of the supply should not have been deemed necessary.

Reasons given in this study for not having water testing carried out were similar for owners of both types of dwellings. The reason most often given, by 49% of participants, was that there was 'no need or no reason' to test. A further 16% of participants stated that they assumed that the water was 'a Tasman District Council supply and should be safe to drink'. These reasons are different to those given in previous studies where 'inconvenience' (Jones et al., 2006), 'inconvenience and cost' (Hexemer et al., 2008), and 'lack of health problems' (Jones et al., 2006) were all cited as main reasons for not performing water testing. These studies, though, were undertaken on owners of private water supplies, not reticulated supplies.

All of the participants in this survey, who had organised for a water test to be carried out, stated that they had done so to ensure that their water was 'safe to drink', as they had concerns about the quality of their water supply. All seven of these participants mentioned that they either believed that they had become sick, or they knew of people who had become sick, from the consumption of drinking-water. These findings confirm previous research which showed that people have had their water tested for reassurance that their water supply is safe to drink (Imgrund, Kreutzwiser, & de Loë, 2011), or because they are aware of health problems related to the consumption of their water supply (Jones et al., 2005).

8.7 Perceptions of water quality

More than 95% of all participants rated the organoleptic properties (taste, colour, and odour) of their water supply as average, good, or very good. Surveys conducted overseas have also shown that people rate the organoleptic properties of their drinking-water highly (Doria et al., 2009; Jones et al., 2005, 2006; Schwartz et al., 1998) with more than 85% of respondents (n=234) in a survey in Ontario rating the taste, smell, and colour of their drinking-water as either good or very good (Jones et al., 2006). A survey undertaken in the Tasman District, to determine levels of customer satisfaction with the facilities provided by the Tasman District Council, also showed that 86% of people in Richmond were either fairly or very satisfied with their water supply (National Research Bureau Ltd, 2012).

Doria (2010), in a review of the factors that influence public perception of drinking-water, concluded that perceptions of water quality are most influenced by the organoleptic properties of a drinking-water supply. This conclusion appears to be confirmed in this survey as more than 90% of participants not only rated the organoleptic properties of the Richmond supply highly, but also rated the safety of the supply highly as well. Only two participants believed the water safety of the Richmond supply to be either poor or very poor. One of these participants had rated the taste, smell, and odour of the supply as poor as well. The other participant believed that they had contracted gastrointestinal illness from drinking Richmond town water and, therefore, believed the safety of the supply to be poor.

A participant's rating of the safety of the water supply did not appear to be related to contamination present in their drinking-water. Of the 34 participants who had total coliforms in their drinking-water, 33 rated the safety of their water supply as average, good, or very good. This misconception also occurred in a survey of private water supplies undertaken in uptown New York where more than 80% of respondents (n=244) stated that they were satisfied with their water supply, yet about a third of these respondents had total coliforms in their water supply (Schwartz et al., 1998).

Although more than 90% of participants rated the organoleptic properties and the safety of their water supply as average or above, only 67% of participants rated their drinking-water as being of average or above value for money. This confirms the findings from the Communitrak™ survey which showed that the main reason why Tasman District residents were not satisfied with their water supply was because of the cost of their water (National Research Bureau Ltd, 2012). More participants with a metered supply (22/50), than participants with a restrictor supply (14/50), thought that their drinking-water was poor or very poor value for money. This difference may have been attributed to the fact that some participants with a metered supply were very aware of the cost of their water as they had just received their water bill, whereas participants with a restrictor supply receive their water bill along with their rates bill at a different time of year.

8.8 Water storage systems

The results from this study showed that participants owned a variety of water storage systems. Tank sizes, tank ages, and tank construction were all found to vary between dwellings. Although there has been no comparable research on the water storage systems of restrictor supplies, an Australian research survey undertaken by Rodrigo et al. (2010) on the storage facilities of private water supplies, sourced from rainwater, demonstrated that tank storage systems also varied between dwellings. Rodrigo et al. (2010) determined that more than 45% of tanks were over 10 years old. This compares to the results of this study where 56% of tanks were found to be greater than 10 years old. In this study tank sizes, for participants with restrictor-only supplies, varied from 1,000 L up to 30,000 L, with most tanks (26/62) being greater than 20,000 L. In the Rodrigo et al. (2010) study, tanks were either <5,000 L (41.5%) or >10,000 L (42.5%). Tank construction was also found to vary with half of all tanks owned by participants in this study being concrete (30/62) (Figure 25) and the other half polyethylene (31/62) (Figure 26). In the Rodrigo et al. (2010) study 28.3% of tanks were polyethylene and 20.6% were concrete.

Figure 26. Polyethylene water storage tank in good condition with lid firmly in place

Although sample size was too small to undertake statistical analyses on dwellings with more than one water storage tank, some analyses were performed on dwellings with just one water storage tank. These analyses were limited in that confounding factors have not been controlled for and sample numbers were small. However, the analyses do provide an indication of some of the factors that might have affected water quality at the kitchen tap for restrictor-only dwellings.

The results of the analyses, when using total coliforms as an indicator of contamination, showed that dwellings with just one storage tank had the same compliance levels with the microbiological criteria stated in the DWSNZ 2005 (Revised 2008) as those dwellings with more than one storage tank ($p=0.467$). In theory, dwellings with more than one tank in series should have had lower levels of contamination than dwellings with just one tank, as the use of more than one water storage tank in series has been shown to reduce levels of contamination (Ashworth, 2004, 2005). However, there were so many other factors that might have caused differences in contamination levels between these dwellings that this difference in actual result compared to expected result is probably not that significant.

Dwellings with tanks older than 10 years had the same compliance levels as those with tanks less than 10 years old (p=0.204) and dwellings with storage tanks that were >20,000 L had the same compliance levels as those that were <20,000 L (p=1.000). Research has shown that tanks can be a site where sediment can accumulate and that this sediment might be responsible for contaminating the water in the tank (Al-Bahry et al., 2011; Martel et al., 2002; Tokajian & Hashwa, 2004). It would be logical, therefore, to expect older tanks, with more sediment build-up to have higher levels of contamination. This was not the case in this study and might have been due to the fact that the sediment and biofilms present in these tanks were acting as a type of bioremediation by forming a micro-ecosystem that excluded the presence of coliform bacteria (Evans, Coombes, Dunstan, & Harrison, 2009; Kim & Han, 2011).

Results from this study, for participants who owned just one storage tank, showed that more concrete tanks than polyethylene tanks were contaminated with total coliforms (p=0.007). The reasons for this increased level of contamination were unclear. It may have been that concrete tanks were older than plastic tanks and had a greater accumulation of sediment at the bottom. The concrete tanks may have had more cracks in them (Figure 25) and had lids that fitted less well than polyethylene tanks. Contamination levels may have been higher in concrete tanks as seven of the 30 concrete tanks were located underground. Underground tanks are known to be more susceptible to the ingress of both faecal and environmental contamination (Cunliffe, 1998) and six of the seven underground concrete tanks in this study were found to be contaminated with total coliforms.

8.9 Maintenance of treatment and water storage systems

Annual maintenance was undertaken on six of the 11 under-bench filtration systems and no maintenance was undertaken on the other five systems. Research has shown that it is essential to maintain home water filter devices regularly as these devices can act as a place where microorganisms can multiply leading to a subsequent loss of water quality (Chaidez & Gerba, 2010; Su et al., 2009; Geldreich et al., 1995; Gray, 2008; MoH, 2005b; Payment, 1989). However, results from this study showed that maintenance did not appear to be related to water quality. Four out of the five systems with no maintenance had no total coliforms, whereas two of the systems that were regularly maintained did have total coliforms present in their water supply. The difference in effectiveness of the water filters found in this study may be unrelated to the maintenance undertaken but solely due to the differences in influent water to these filters or to the type of filter used.

Inspection and cleaning of water storage tanks was seldom undertaken by participants with a restrictor-only supply in this study as nearly 40% of tanks were never inspected and 92% of participants with this supply type never cleaned their water storage tanks. Although previous studies have shown that owners of water storage tanks seldom clean their water storage tanks the percentage of participants that did not clean their tanks was even higher in this study than in previous studies (Abbott et al., 2006; Fleming, 2000; Rodrigo et al., 2010; Verrinder & Keleher, 2001). The high percentage of participants in this study that did not clean their tanks may well have been caused by lack of knowledge as participants might have been be unaware of the need for regular tank maintenance.

8.10 Knowledge of water supply

It was evident from the results relating to the questions concerning participants' knowledge of the Richmond urban water supply that participants were unaware of either the treatment status of the Richmond supply or of the public health grading. Only 10% of participants with a metered or a restrictor-only dwelling knew that the water supply was untreated and 5% knew the public health grading for the supply. The low numbers of participants that knew the treatment status of the water supply was a surprise as a recent Communitrak^{TM} survey of the Tasman District determined that 95% of participants in the survey had seen, read or heard of 'Newsline – The Mag' and approximately 50% had seen, read, or heard of the "Long-Term Plan' and 'Annual Plan' (National Research Bureau Ltd, 2012). As these documents contain information regarding the treatment status of the Richmond water supply it was a surprise that more participants were not aware of this fact (TDC, 2012a, 2012b). It was less surprising that most participants did not know the grading of the Richmond supply as this information is less well publicised.

8.11 Survey response rates

Even though the response rate for metered dwellings (66%) was lower than that for dwellings with a restrictor supply (98%), the response rate for this survey was higher than expected and higher than has been recorded for previous similar surveys (Hexemer et al., 2008; Jones et al., 2006). These high response rates may have been due to the use of an interviewer, as personal interviews are known to increase the participation rate of surveys when compared to using telephone, mail, or internet survey techniques (Fowler, 2009; Suskie, 1996).

8.12 Demographic data

There was no demographic data available for Richmond so demographic information from this study was compared to that for the Tasman District as a whole. More females than males took part in this survey (64 females compared to 36 males). Over 40% of all participants were in the 60+ age category and only three participants were under 40 years old. This differs markedly from the statistical age variation in Tasman as a whole where the median age of people is 40.3 years old and 13.6% of people are over 65 years of age (Statistics New Zealand, 2007). Ethnicity of participants was similar to that for the Tasman District with 90% of participants belonging to the European ethnic group compared to 82.7% for the Tasman District (Statistics New Zealand, 2007). Maori participation rate was lower in this survey (2%) than in the Tasman District as a whole (7.1%).

Home ownership was higher in this survey (92%) than in the Tasman region as a whole (62.7%). Occupation of participants varied significantly between types of water supply (p=0.032) and was also different to that for people in the Tasman district as a whole. In the Tasman District most common occupation was 'labourer' whereas no participants with a restrictor-only supply and only three participants with a metered supply stated this as an occupation. 'Professional' was the most common occupation for participants with a restrictor-only supply compared to 'retired' for participants with a metered supply. Land area varied between supply types with metered dwellings being on a smaller land area than dwellings with a restrictor supply ($p<0.0005$). This was an expected result as metered dwellings were in urban Richmond whereas restrictor dwellings were in semi-urban or rural Richmond. Although restrictor-only dwellings had more bedrooms ($p<0.0005$) than metered dwellings the number of people living at each dwelling did not vary across supply type ($p=0.976$).

The reason that the demographic information obtained from this study was different to that obtained from the Tasman District may have been because this study only sampled dwellings in Richmond, and Richmond may have had different demographic data to that of Tasman District as a whole. Alternatively, the sample taken may have been biased. This bias may have occurred due to the time of day when sampling occurred. Although sampling was undertaken seven days a week, people who work at daytime jobs would not have been available for sampling on weekdays. This may have accounted for the large percentage of over 60 year olds in the sample and for the fact that more females than males took part in this survey.

8.13 Limitations to the study

- Sample size. Sample size was a limitation in this study. Limited statistical analyses could be performed on the results obtained relating to water storage systems as there were too few cases in each category to provide meaningful results. Sample size of dwellings with a restrictor-supplemented supply was also too small to be able to carry out any statistical analyses.
- Water sampling. More than one water sample should have been taken from each dwelling, as taking more than one sample would have provided a more accurate indication of water quality. More water samples could have been taken at each visit or more samples could have been taken over a longer period of time, such as a year, to obtain an indication of changes in water quality over time.
- Respondent bias. There may well have been respondent bias in this survey due to time of day and year that sampling was carried out and due to the method of sampling utilised. As sampling was undertaken during the daytime it may have been that people who spend more time at home during the day, such as retired people and home makers, were over-represented in this study.
- Comparison of these findings to other populations. As each water supply is unique in its choice of source, treatment, and type of distribution network, the results from this study may not be applicable to other populations.
- Ideally, a water sample would have been taken from the distribution network before the meter or the restrictor for all dwellings sampled. Water quality before the meter/restrictor could then have been compared to water quality at the kitchen tap. This would have provided a clearer indication of the source of the contamination.
- Questions relating to participants' perceptions of their water supply were subjective in nature. To increase the value of these questions a 'standard' water sample, such as bottled water, could have been used. Participants would then have been able to compare the organoleptic properties of their Richmond water supply with this 'standard' water sample.

8.14 Future studies

- Another survey could be undertaken whereby all of the restrictor-only dwellings would be re-visited and re-interviewed with a different questionnaire to ascertain why some dwellings had total coliform contamination and others did not. Water sampling would be taken in the distribution network, before the restrictor, at the inlet to the tank, in the tank, at the outlet of the tank, and at the kitchen tap. Multiple sampling points would provide a clearer indication of the source of the contamination.
- A further study could also be undertaken, when the new treatment plant has been installed, to see if the new plant has made any difference to the levels of contamination present in the households that took part in this study.
- It would also be interesting to conduct the same study, but on a chlorinated supply to determine if there was any difference in levels of contamination between a chlorinated and a non-chlorinated supply.
- As stated previously, it would be beneficial to take more than one water sample from each dwelling. More than one sample could be taken at one visit, or multiple visits could be made over a longer period of time to obtain multiple water samples.
- A further study could be undertaken whereby more restrictor-supplemented dwellings were sampled in order to increase sample numbers.
- Participants in this study who had used a supplementary water supply were still paying for 2 m^3 per day of Richmond town water. It is unclear why these participants supplemented their water supply whilst still paying for town water, as there are costs involved in having an extra water source and water quality appears to be reduced. It would, therefore, be interesting to determine why people chose to supplement their town water supply with water from another source.

9 Conclusion

This study has provided some interesting, although slightly conflicting results. For the Richmond urban water supply scheme, when total coliforms were used as an indicator of contamination, water quality was found to not be the same for metered dwellings compared to dwellings with a restrictor-only supply ($p<0.0005$). More restrictor-only supplies had total coliforms in their drinking-water supply than dwellings with a metered supply. Furthermore, 16% of dwellings with a metered supply and 52% of dwellings with a restrictor-only supply were found to not have a potable water supply and to not comply with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 total coliform per 100 ml.

In contrast to these results, when *E.coli* was used as an indicator of contamination, metered dwellings were found to have the same microbiological water quality as dwellings with a restrictor-only supply ($p=0.242$). All metered dwellings and 94% of restrictor-only dwellings sampled at the kitchen tap were found to have a drinking-water supply that was 'potable' and complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 *E.coli* per 100 ml.

The *E.coli* results demonstrated that it was possible for a reticulated drinking-water supply, sourced from groundwater, to be delivered to consumers without treatment or residual disinfection. However, the total coliform results indicated not only that the supply might be contaminated from environmental sources but also that the use of a restrictor supply might lead to a loss in drinking-water quality. The exact reason for the presence of total coliforms in the supply was not determined, but it appeared likely that the reason for the difference in water quality between metered and restrictor dwellings was due to the fact that owners of reticulated supplies had to store their water prior to use.

No participants with a metered supply and 18% of participants interviewed with a restrictor supply supplemented their Richmond water supply with water from another source. Supplementary sources included roof-collected rainwater, spring, and well water. Water test results indicated that supplementing a water supply with water from another source caused a loss of microbiological water quality.

Utilisation of home treatment devices was low in this study with only 14 participants having installed any form of water treatment. Under-bench filtration was the type of treatment system most often installed by participants.

Water testing had only been undertaken by seven participants with a restrictor-only supply. These participants had tested their water to determine if the water was safe to drink. The main reason given by all participants for not testing their water supply was that there was ‘no reason or no need’ to test.

Results showed that more than 90% of participants were happy with the safety and the organoleptic properties of the Richmond water supply. Fewer participants were happy with the cost of their water supply as almost a third of participants believed their water supply to be of poor or very poor value for money. Participants’ knowledge of the treatment status and public health grading of the Richmond supply was minimal as only 10% of participants with a metered or a restrictor-only dwelling knew that the water supply was untreated and 5% knew the public health grading for the supply.

A variety of water storage systems were owned by participants with a restrictor-only supply. Over 80% of participants owned one water storage tank. Tank sizes varied from 1,000L up to 30,000 L with just over 40% of tanks being greater than 20,000 L. More than half of the tanks owned (35/62) were over ten years old; 30 were concrete, 31 polyethylene, and one was fibreglass. Seven tanks were situated underground, 54 were on the ground, and one was raised above the ground. Inspection and cleaning of water storage tanks was seldom undertaken.

To summarise, this study has demonstrated that, when using *E.coli* as an indicator of contamination, drinking-water quality was the same for metered compared to restrictor-only dwellings. The results for *E.coli* have shown it is possible to provide a potable supply of water via a reticulated network without treatment or the presence of residual disinfection. In contrast, the total coliform results have demonstrated that there might be issues with the use of restrictor drinking-water supplies. These issues were likely to be caused by the fact that owners of these supplies had to store their water prior to use.

Although there have been no reported waterborne outbreaks to date associated with the Richmond water supply and the supply has been of good quality, the installation of the new water treatment plant will be beneficial to the Richmond supply, as it will provide a further barrier in the supply network to ensure that consumers are supplied with a potable supply of drinking-water.

To ensure that dwellings with a restrictor supply have the same microbiological water quality as dwellings with a metered supply, owners of restrictor supplies need to be provided with more information on the set-up, design, and maintenance of water storage systems. It would also be advisable for owners of these systems to have their water tested, at least once every six months, so that any changes in water quality could be noted and remedial action could then be undertaken. All participants with a restrictor-supplemented water supply should have a suitable home water treatment device fitted in their dwelling to ensure that water supplied at the kitchen tap is potable.

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Appendix A. Strength of association for outbreaks of waterborne disease

The Public Health Laboratory Service (PHLS) has provided a framework for determining the likelihood that an outbreak is of waterborne origin. Strength of association, between water exposure and illness, is determined using epidemiological and microbiological evidence. Evidence is categorised (A, B, C, or D) and then summarised to determine whether the outbreak was strongly, probably, or possibly associated with exposure to water (Public Health Laboratory Service, 1996).

Microbiology/water quality

A. Pathogen identified in clinical cases is also found in water
B. Water quality failure and/or water treatment problem of relevance but outbreak and pathogen is not detected in water

Epidemiology

C. Evidence from an analytical (case control or cohort) study demonstrates association between water and illness
D. Descriptive epidemiology suggests that the outbreak is water related and excludes obvious alternative explanations

Strength of association

Strongly associated if (A + C) **or** (A + D) **or** (B + C);

Appendix B. Questionnaire

A comparison of the microbiological quality of drinking-water of urban and semi-urban dwellings in the Richmond district of New Zealand

Interviewer Administered Questionnaire

Study ID Number________________________ Date of interview _______ /________/2012

Name of participant ____

Address ____

Home phone ____________ Mobile ________________ Email ___________________

Q1 **Check, prior to visiting, that the dwelling is supplied with drinking- water from the Richmond town water supply?**

Yes ☐ No ☐

Q2 **What type of water supply does your dwelling have?**

On-demand, metered ☐ Restricted, low-flow ☐ Don't know ☐ Other ☐

Please specify ____

Q3 **How would you rate the quality of your drinking-water supply based on the following characteristics?**

Taste	Very good ☐	Good ☐	Average ☐	Poor ☐	Very poor ☐
Odour	Very good ☐	Good ☐	Average ☐	Poor ☐	Very poor ☐
Colour	Very good ☐	Good ☐	Average ☐	Poor ☐	Very poor ☐
Safety	Very good ☐	Good ☐	Average ☐	Poor ☐	Very poor ☐
Value for money	Very good ☐	Good ☐	Average ☐	Poor ☐	Very poor ☐

Q4 **Is the drinking-water supplied to your household by the Tasman District Council:**

Treated ☐ Untreated ☐ Don't know ☐

Q5 **Are you aware of the current public health grading assigned to the Richmond urban water supply?**

Yes ☐ No ☐

Q6 **Which of the following information sources have you ever accessed to find out information about your drinking-water supply?**

Tasman District Council ☐ NMDHB ☐ Register of Drinking Water supplies ☐

Annual Review of Drinking-water quality ☐ Drinking-water New Zealand web site ☐

None ☐

Q7 **The water from your kitchen tap is used for which of the following purposes:**

Drinking ☐ Brushing your teeth ☐

Mixing drinks ☐ Making ice ☐

Food preparation ☐ Other ☐

Please specify ____

Q7a **If you don't drink water from your kitchen tap, where do you get your drinking-water from?**

Don't drink water ☐ Other tap in house ☐ Buy bottled water ☐ Other source ☐

Please specify ____

WATER TESTING

QA1 Have you ever had your water supply tested?

Yes ☐ No ☐ Don't know ☐

QA1a If yes to QA1, what test(s) did you have performed (more than one box can be ticked)?

E.coli count ☐ Total coliform count ☐ *Salmonella* ☐ *Giardia* ☐

Hardness ☐ *Cryptosporidium* ☐ pH ☐ Don't know ☐ Other ☐

Please specify____

QA1b If yes to QA1a, how often have you performed this testing?

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ Don't know ☐ Other ☐

Please specify ____

QA1c If yes to QA1a, when was the last time that you had the water tested?

Please specify ____

QA1d If yes to QA1a, why did you have your water tested?

Please specify ____

QA1e If no to QA1a, what is/are the reason(s) for you not performing water testing?

Please specify____

____

TREATMENT QUESTIONS

QB1 Do you have a water treatment device installed on your household water supply?

Yes ☐ No ☐ Don't know ☐

QB1a If yes to QB1, what type or type(s) of treatment(s) are undertaken?

Fine particle filtration	☐	Ceramic filter	☐
Coarse particle filtration	☐	Boiling water	☐
Polypropylene filtration	☐	Activated carbon	☐
Ultraviolet light treatment	☐	Hydrogen peroxide	☐
Ion exchange filter	☐	Chlorination	☐
Reverse osmosis	☐	pH correction	☐
Ozone	☐	Don't know	☐

Other ☐ Please specify ____

QB2 If yes to QB1, how long ago was the water treatment system installed?

Under 6 months	☐	6-12 months	☐	13-24 months	☐
25 months – 5 yrs	☐	> 5 years	☐	Don't know	☐

Other ☐ Please specify ____

QB3 If the water supply is treated, at what point does treatment occur?

Please specify ____

QB4 If yes to QB1, how often is treatment undertaken?

Continuously	☐	Daily	☐	Weekly	☐	Monthly	☐
6 Monthly	☐	Yearly	☐	Don't know	☐	Other	☐

Please specify ____

QB5 If yes to QB1, how often is maintenance carried out on the treatment system?

Continuously	☐	Daily	☐	Weekly	☐	Monthly	☐
6 Monthly	☐	Yearly	☐	Don't know	☐	Never	☐
Other	☐						

Please specify ____

QB5a If yes to QB5, who carries out this maintenance?

Yourself ☐ Family member ☐ Neighbour ☐ Friend ☐ Service technician ☐

Other ☐ Please specify ____

SUPPLY QUESTIONS

QC1 **Do you ever supplement your Council drinking-water supply with water from another source?**

Yes ☐ No ☐ Don't know ☐

QC2 **If yes (to QC1) what type of water source have you utilized?**

Spring ☐ Bore/well ☐ Roof-collected rainwater ☐ Water tanker ☐ River ☐

Stream/creek ☐ Dam/Reservoir ☐ Don't know ☐ Other ☐

Please specify ____

QC3 **How often have you utilized this/these supplementary water source(s)?**

Continuously ☐ Daily ☐ Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐

Don't know ☐ Other ☐ Please specify ____________________________

DEMOGRAPHIC DETAILS

QD1 **How many people live at this dwelling?** ☐

Ages: < 15 years☐ 15 -19 years☐ 20-29 years ☐ 30-39 years ☐

40-49 years ☐ 50-59 years ☐ 60 years and over ☐

QD2 **How many bedrooms does the dwelling have?**

None ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ >5 ☐

QD3 **What size of land area is your dwelling on?**

<1 acre ☐ 1-10 acres ☐ 11-20 acres ☐ 21-50 acres ☐ >50 acres ☐

Participant Details

QD4 **Age**: < 15 years ☐ 15 -19 years ☐ 20-29 years ☐ 30-39 years ☐

40-49 years ☐ 50-59 years ☐ 60 years and over ☐

QD5 **Sex** Male ☐ Female ☐

QD6 **Ethnicity** Maori ☐ European ☐ Pacific ☐ Other ☐

QD7 **Occupation** ____

QD8 **How long have you lived at this address?**

<1 year ☐ 1-5 years ☐ 6-10 years ☐ >10 years ☐ Don't know ☐

QD9 **Are you the owner of this dwelling?**

Yes ☐ No ☐ Other ☐ Please specify____________________________

QUESTIONS FOR RESPONDENTS WITH A SUPPLEMENTARY WATER SUPPLY AND FOR RESPONDENTS WITH A RESTRICTOR, LOW FLOW SUPPLY

QE1 Did you set up your own drinking water supply system?

Yes ☐ No ☐ Partially/in part ☐ Don't know ☐

QE1a If no, who did set up your drinking water supply?

____

QE2 How many water storage tanks do you have, if any?

None ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ >4 ☐ Don't know ☐

QE2a What is the water storage capacity of each tank?

Please specify

____

QE2b What is the total water storage capacity of your storage tanks?

<1,000 L ☐ 1,001-10,000 L ☐ 10,001-20,000 L ☐ >20,000 L ☐ Don't know ☐

QE3 What is/are your water storage tank(s) constructed from?

Concrete ☐ Plastic ☐ Fibreglass ☐ Galvanised Iron/steel ☐

Corrugated iron ☐ Don't know ☐ Other ☐

Please specify ____

QE4 Where is/are your water storage tank(s) located?

At ground level ☐ Below ground level ☐ Raised above ground ☐

Don't know ☐ Other ☐ Please specify __________________________________

QE5 How old is/are your water storage tank(s)?

<1 year ☐ 1-5 years ☐ 6-10 years ☐ >10 years ☐ Don't know ☐

QE6 **Is/are the storage tank(s) provided with an inspection opening?**

Yes ☐ No ☐ Don't know ☐ Other ☐ Specify ________________________

QE6a **Is/are the inspection opening(s) firmly in place?**

Yes ☐ No ☐ Don't know ☐ Other ☐ Specify __________________________

QE7 **How often do you inspect the water in your storage tank(s)?**

Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Never ☐ Other ☐ Please specify ________________________

QE8 **How often is/are the water storage tank(s) cleaned?**

Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Never ☐ Other ☐ Please specify ________________________

QE8a **If yes to QE8, who undertakes this cleaning?**

Yourself ☐ Family member ☐ Friend ☐ Neighbour ☐ Service technician ☐
Other ☐ Please specify ____

QE9 **Which of the following are present on or in your water tank(s)?**

Tank vacuum system ☐ Tank inlet screen/mesh ☐ Water depth indicators ☐

Air vents ☐ Floating hose draw-off ☐ Calmed inlet/drop inlet pipe ☐

Tank sock/bag in tank ☐ Other ☐ Specify ______________________________

RAINWATER SYSTEMS ONLY

QF1 Which of the following measures do you have installed in your rainwater system?

Leaf slide/eater/beater ☐ First flush diverter ☐ Gutter guard screens ☐

Brush in gutter ☐ Tank rain-catcher filter ☐ Other ☐ Specify _______________

QF2 What is your roof material constructed from?

Galvanised iron ☐ Painted iron ☐ Asbestos cement ☐ Colour steel ☐
Butynol ☐ Concrete tile ☐ Fibrolite ☐ Decramastic tiles ☐ Other ☐

Please specify ____

QF3 What is the roof guttering constructed from?

Galvanised iron ☐ Painted iron ☐ Copper ☐ PVC (plastic) ☐

Don't know ☐ Other ☐ Specify____________________________________

QF4 How often is the roof cleaned?

Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Never ☐ Don't know ☐ Other ☐ Specify ____________________________

QF5 Who undertakes this cleaning?

Yourself ☐ Family member ☐ Friend ☐ Neighbour ☐ Service technician ☐

Don't know ☐ Other ☐ Specify ____________________________________

QF6 How often is the roof guttering cleaned?

Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐ Never ☐
Don't know ☐ Other ☐ Specify ___________________________

QF7 Who undertakes this cleaning?

Yourself ☐ Family member ☐ Friend ☐ Neighbour ☐ Service Technician ☐
Other ☐ Specify _______________________________________

QF8 How many trees or branches are overhanging parts of the roof and/or gutters?

None ☐ A few ☐ A moderate amount ☐ Numerous ☐ Unsure ☐

QF9 How often have you seen or heard evidence of animals on your roof?

Never ☐ A few times ☐ Often ☐ Very often ☐ Unsure ☐

QF10 How often have you seen or heard evidence of birds on your roof or on overhanging trees?

Never ☐ A few times ☐ Often ☐ Very often ☐ Unsure ☐

GROUNDWATER BORE/WELL

QG1 Where is your groundwater bore/well located (in relation to land use, structures, septic tank etc)?

____

____

QG2 How was your groundwater bore/well made?

Dug ☐ Drilled ☐ Don't know ☐ Other ☐ Specify______________________

QG3 How long ago was your well/groundwater bore drilled/dug?

<1 year old ☐ 1-5 years old ☐ 6-10 years old ☐ >10 years old ☐ Don't know ☐

QG4 What depth is your groundwater bore/well?

1-5 m ☐ 6-10m ☐ 11-20m ☐ >20m ☐ Don't know ☐

QG5 Which of the following measures are present on or around your groundwater bore/well?

Cement grout seal around casing ☐ Sampling tap ☐

Sloping concrete apron ☐ Sealed cap ☐

Check valves (to prevent backflow) ☐ Raised opening ☐

Fencing to exclude stock ☐ Air vent ☐

Screen (on end of casing) ☐ Other ☐

Please specify ____

QG6 If present, how often do you check to see if the sealed cap is firmly in place?

Weekly ☐ Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify __________________________________

QG7 If present, how often do you check the condition of the sealed apron around your bore?

Weekly ☐ Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐
>Yearly ☐ Don't know ☐ Other ☐ Specify __________________________

QG8 **If present, how often do you check the fencing around the bore/well?**

Weekly ☐ Monthly ☐ 3 monthly ☐ 6 monthly ☐ Yearly ☐
>Yearly ☐ Don't know ☐ Other ☐ Specify ____________________________

QG9 **Are there any other maintenance tasks that are undertaken on your groundwater bore/well?**

Yes ☐ No ☐ Don't know ☐

QG10 **If yes, what are these tasks?**

____

____

QG11 **If yes, how often are these tasks undertaken?**

____

____

QG12 **If yes, who undertakes these tasks?**

Yourself ☐ Family member ☐ Friend ☐ Neighbour ☐ Service technician ☐
Other ☐

Please specify____

SPRING

QH1 Where is your spring located (in relation to land use, structures, septic tank)?

____

____

QH2 Which of the following measures are present on or around your spring?

Methods to divert surface water entering the spring ☐ Spring box ☐

Screen on the intake pipe ☐ Fencing to exclude stock ☐ Other ☐

Please specify ____

QH3 If present, how often do you check the condition of the spring box?

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify ________________________________

QH4 If present, how often do you check the inlet screen?

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify ________________________________

QH5 If present, how often do you check the fencing around the spring?

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify ________________________________

QH6 Are there any other maintenance tasks that are undertaken on your spring?

Yes ☐ No ☐ Don't know ☐

QH7 If yes, what are these tasks?

____

____

QH8 If yes, how often are these tasks undertaken?

____

QH9 If yes, who undertakes these tasks?

Yourself ☐ Other family member ☐ Friend ☐ Neighbour ☐ Service technician ☐ Other ☐ Specify ________________________________

SURFACE WATER

QJ1 **Where is your surface water source located (in relation to land use, structures, septic tank etc)?**

____

____

QJ2 **Which of the following measures are present at your surface water inlet?**

Attachments to prevent inlet being dislodged ☐ Screen on the intake pipe ☐

Fencing to exclude stock ☐ Other ☐ Specify ________________________

QJ3 **How often do you check the location of your inlet?**

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify ______________________________

QJ4 **If present, how often do you check the inlet screen?**

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify ______________________________

QJ5 **If present, how often do you check the fencing around the inlet?**

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ >Yearly ☐

Don't know ☐ Other ☐ Specify ______________________________

QJ6 **Are there any other maintenance tasks that are undertaken on your surface water source?**

Yes ☐ No ☐ Don't know ☐

QJ7 **If yes, what are these tasks?**

____

QJ8 **If yes, how often are these tasks undertaken?**

____

QJ9 **If yes, who undertakes these tasks?**

Yourself ☐ Family member ☐ Friend ☐ Neighbour ☐

Service technician ☐ Other ☐ Specify ____________________________

WATER CARRIER SUPPLIES

QK1 **How often do you top up your water tank with water from a water carrier?**

Weekly ☐ Monthly ☐ 6 monthly ☐ Yearly ☐ Don't know ☐ Other ☐

Please specify ____

QK2 **How much water do you get delivered each time you top up your tank?**

<$1m^3$ ☐ 1.1-$5m^3$ ☐ 5.1-$10m^3$ ☐ >$10m^3$ ☐ Don't know ☐ Other ☐

Please specify ____

QK3 **Who delivers the water to your tank?**

Yourself ☐ Other family member ☐ Friend ☐ Neighbour ☐

Professional water carrier ☐ Don't know ☐ Other ☐

Please specify

____

QK4 **If it is a professional company, please specify company name:**

Name of water carrier____

QK5 **Is your water delivered by a Registered drinking-water carrier?**

Yes ☐ No ☐ Don't know ☐

QK6 **Do you receive a delivery statement when the water is delivered?**

Yes ☐ No ☐ Don't know ☐

QK7 **Do you know the water source?**

Yes ☐ No ☐ Don't know ☐

If yes, please specify____

QK8 **What class of water do you get delivered?**

Class 1a ☐ Class 1b ☐ Class 2 ☐ Don't know ☐ Other ☐

Please specify____

Appendix C. Laboratory

A laboratory was set up at the researcher's home using equipment supplied by Massey University.

Equipment and materials utilised in the laboratory:

- Incubator set to 35^0C ± 0.5^0C
- Thermometers
- Quanti-tray® sealer
- 365 nm wavelength ultraviolet light with a 6 watt bulb
- 97-well Quanti-Trays®/2000 (IDEXX Laboratories)
- Colilert®-18 Reagents (IDEXX Laboratories)
- Latex gloves
- 70% Alcohol wipes
- Disinfectants
- Sterile 120 ml graduate plastic bottles
- Vivid marker pen
- *Escherichia coli* (NZRM 916 – nutrient agar culture)
- *Klebsiella pneumonia* (NZRM 482 – nutrient agar culture)
- *Pseudomonas aeruginosa* (NZRM 981 – nutrient agar culture)
- Loop and inoculating needles
- Biohazard bags
- Safety glasses
- First aid kit

Equipment and materials used for sampling:

- 70% alcohol wipes
- Latex gloves
- Sterile 250 ml plastic bottles
- Small chilly bin
- Ice packs
- Vivid marker pen
- First aid kit

Appendix D. Dual water sampling

To ensure that the results recorded by the researcher were valid, dual testing of ten water samples was undertaken in conjunction with the Tasman District Council and the Cawthron Institute. The Council arranged for a Downer service agent to sample the drinking-water from ten dwellings at the same time as the researcher sampled these dwellings.

For the purposes of dual sampling the Downer service agent aseptically collected 250 ml of water from an outdoor tap into a sterile 250 ml plastic bottle. This sample was then halved and approximately 120 ml was poured into a graduated sterile labelled 120 ml plastic bottle. The Downer agent sent the sample in the 120 ml bottle to the Cawthron Institute to be enumerated for total coliforms and *E.coli* using the Colilert®-18 method. The sample in the 250 ml bottle was taken by the researcher and enumerated using the Colilert®-18 method as described in the method section of this report.

Microbiological results of 'dual sampling'

The results of the dual sampling undertaken with the Cawthron Institute are shown in Table D1. The researcher's results are the same as the Cawthron's for eight of the ten dwellings tested. For the other two dwellings the researcher found more total coliforms per 100 ml than the Cawthron and for one dwelling the researcher recorded one *E.coli* per 100 ml present when the Cawthron found <1 *E.coli* per 100 ml.

Table D1. Results of dual microbiological testing with the Cawthron Institute.

		Total coliforms per 100 ml		*E.coli* per 100 ml	
ID	**Supply type**	**Researcher**	**Cawthron**	**Researcher**	**Cawthron**
D1	Metered	<1	<1	<1	<1
D10	Metered	<1	<1	<1	<1
D2	Restrictor-only	<1	<1	<1	<1
D3	Restrictor-only	<1	<1	<1	<1
D5	Restrictor-only	<1	<1	<1	<1
D6	Restrictor-only	<1	<1	<1	<1
D8	Restrictor-only	<1	<1	<1	<1
D9	Restrictor-only	<1	<1	<1	<1
D7	Restrictor-only	9.8	4.0	<1	<1
D4	Restrictor-supplemented	17.5	7.0	1.0	<1

Appendix E. Information sheet for participants

Massey University
COLLEGE OF SCIENCES

INSTITUTE OF FOOD, NUTRITION
AND HUMAN HEALTH
Te Kura Hangarau o
Kai-oranga-ā-tāngata
Private Box 756
Wellington
New Zealand
T 64 4 801 2794
F 64 4 801 4994
www.massey.ac.nz

A comparison of the microbiological quality of drinking-water of urban and semi-urban dwellings in the Richmond district of New Zealand

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Hi, my name is Lucy Thompson. I am a student at Massey University studying for a Masters in Health Science. This year I am doing my thesis study which aims to compare the microbiological quality of drinking-water of dwellings with an on-demand, metered water supply to dwellings with a restrictor, low-flow supply, where both dwelling types are supplied from the Richmond urban water supply scheme. To determine if water quality is the same for both types of dwelling, I am going to do a cross-sectional survey of randomly selected dwellings in the Richmond area.

If you agree to participate in this study you will be asked a few questions relating to your water supply. A water sample will then be taken from your kitchen tap for a free microbiological analysis. You will receive the results of this test within 72 hours of sampling. The whole interview process should take no more than 10-15 minutes of your time.

You are under no obligation to participate in this study. If you do decide to participate, you have the right to decline to answer any particular question. You may ask questions about this study at any time during your participation and you can withdraw from the study at any point up until submission of the first draft of the final report on September 3rd 2012. Your name and contact details will not be made public and the final report will contain no personal details that could identify you as having taken part in this study.

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named below is responsible for the ethical conduct of this research. If you have any concerns about this research that you wish to raise with someone other than the researcher, please contact either Professor John O'Neill, Director, Research Ethics, telephone 03 350 5249, email: humanethics@massey.ac.nz or Mr Stan Abbott, Senior lecturer, Microbiology & Communicable Diseases, telephone 04 801 2794 ext 6797, email: S.E.Abbott@massey.ac.nz

Thank you

Lucy Thompson
Ph 544 3949

Appendix F. Participant consent form

Massey University
COLLEGE OF SCIENCES

INSTITUTE OF FOOD, NUTRITION AND HUMAN HEALTH
Te Kura Hangarau o Kai-oranga-ā-tāngata
Private Box 756
Wellington
New Zealand
T 64 4 801 2794
F 64 4 801 4994
www.massey.ac.nz

A comparison of the microbiological quality of drinking-water of urban and semi-urban dwellings in the Richmond district of New Zealand

Participant informed consent form

I have read the participation information sheet provided by Lucy Thompson and have had the details of the study explained to me. I have had the opportunity to discuss this research survey with the researcher and have had time to consider whether I would like to take part in this survey. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I understand that taking part in this survey is voluntary and that I may withdraw at any time up until submission of the first draft of the final report on September 3rd 2012.

I ………………………………………………………………….. (full name) hereby consent to take part in this study.

Signed …………………………………………… Date …..……/…………../2012

Appendix G. Visit Log

Visit Log

ID Number	Address	Name	Phone number	Visited	Date	Time	Outcome	Comment
				Visit 1	/ /12			
				Visit 2	/ /12			
				Visit 1	/ /12			
				Visit 2	/ /12			
				Visit 1	/ /12			
				Visit 2	/ /12			
				Visit 1	/ /12			
				Visit 2	/ /12			
				Visit 1	/ /12			
				Visit 2	/ /12			

Appendix H. Result reporting letters

Example of result reporting letter for participant with no microbiological contamination present in their drinking-water supply

Massey University
WELLINGTON

MICROBIOLOGICAL WATER QUALITY STUDY

Study ID Number: R1 **Water Sample:** Kitchen tap

Name **Address**:

Dear

The microbiological analysis of the water sample taken on the 3.05.12 show the following results:

Sample ID	Sample type	Total coliforms (per 100ml)	Escherichia coli (per 100ml)
R1	Kitchen tap	<1	<1

The total coliform result indicates that at the time of sampling there was no environmental contamination (e.g. soil and vegetation) of the water. The *E.coli* result indicates that there was no faecal contamination present either. Thank you for participating in this study.

Lucy Thompson

(4.05.12)

Example of result reporting letter for participant with microbiological contamination present in their drinking-water supply

Massey University
WELLINGTON

MICROBIOLOGICAL WATER QUALITY STUDY

Study ID Number: R49 **Water Sample:** Kitchen tap

Name **Address**:

Dear

The microbiological analysis of the water sample taken on the 13.06.12 show the following results:

Sample ID	Sample type	Total coliforms (per 100ml)	*Escherichia coli* (per 100ml)
R49	Kitchen tap	157.6	4.1

The total coliform result indicates that at the time of sampling there was environmental contamination (e.g. soil and vegetation) of the water. The *E.coli* result indicates that there was faecal contamination as well. Please see the enclosed Ministry of Health booklet on how to safeguard your drinking water supplies. Thank you for participating in this study.

Lucy Thompson
(14.06.12)

Example of result reporting letter for participant with a filter tap

MICROBIOLOGICAL WATER QUALITY STUDY

Study ID Number: R30 **Water Sample:** Kitchen tap

Name **Address**:

Dear

The microbiological analysis of the water sample taken on the 24.05.12 show the following results:

Sample ID	Sample type	Total coliforms (per 100ml)	*Escherichia coli* (per 100ml)
R30	Kitchen tap	7	<1
R30f	Filter tap	<1	<1

The total coliform result from the kitchen tap indicates that at the time of sampling there was environmental contamination (e.g. soil and vegetation) of the water. The *E.coli* result from the kitchen tap indicates that there was no faecal contamination present. There was neither total coliform nor *E.coli* contamination present in the water sample taken from the filter tap. Please see the enclosed Ministry of Health booklet on how to safeguard your drinking water supplies. Thank you for participating in this study.

Lucy Thompson
(25.05.12)

Appendix I. Justification for microbiological reporting categories

The results of microbiological water testing have been reported in this study as being either compliant or non-compliant with the criteria stated in the DWSNZ 2005 (Revised 2008). Drinking-water samples containing less than one *E.coli* or less than one total coliform per 100 ml are compliant with the DWSNZ 2005 (Revised 2008) and are ‘potable’. Results showing one or more *E.coli* or total coliforms per 100 ml are deemed non-compliant and non-potable (MoH, 2008).

Reporting the microbiological results from this study as being either compliant or non-compliant with the DWSNZ 2005 (Revised 2008) does not provide an indication of the range of results recorded. It is, however, difficult to choose a set of categories by which the results could be reported as there is no internationally recognized precedent on how to do this. Studies have been undertaken, both in New Zealand and overseas, that have reported the microbiological water testing results in various categories. However, each of these studies differs in some major way to this study (Abbott et al., 2006; Bacci & Chapman, 2011; Simmons et al., 2001)

In New Zealand, Abbott et al. (2006) reported microbiological testing results in categories from 0-10, 10-20, 20-60, 60-100, 100-200, and >200 *E.coli* or total coliforms per 100 ml. However, these results related to private water supplies sourced from roof-collected rainwater. Another study, undertaken to determine the microbiological quality of roof-collected rainwater in New Zealand, reported results by showing value ranges and median counts for each microorganism studied (Simmons et al., 2001).

Studies have also been undertaken overseas that report the microbiological results of drinking-water (Bacci & Chapman, 2011). In Ireland, a study into the microbiological quality of private water supplies from boreholes, reported microbiological results in five categories: <1, 1-5, 6-10, 11-100, and >100 *E.coli* or total coliforms per 100 ml. These categories were chosen by Bacci and Chapman (2011) as they were the same categories used by the Environmental Protection Agency (EPA) in reports on national data for groundwater quality in Ireland (Environmental Protection Agency [EPA], 2006). However, these results related to private water supplies (Bacci & Chapman, 2011) and to groundwater (EPA, 2006), not reticulated drinking-water supplies.

As this study has been undertaken in New Zealand and is based on a reticulated supply that should be taking ‘all practicable steps to comply with the DWSNZ’ reporting categories to show the range of microbiological results obtained have been chosen based on information found in the DWSNZ 2005 (Revised 2008). Three reporting categories have been chosen; <1 cfu/100 ml, 1-9 cfu/100 ml, and ≥10 cfu/100 ml.

The first category of <1 *E.coli* or <1 total coliform per 100 ml is based on compliance with the DWSNZ 2005 (Revised 2008). The second and third groups of 1-9 *E.coli* or total coliforms per 100 ml and ≥10 *E.coli* or total coliforms per 100 ml are based on the transgression criteria in the DWSNZ 2005 (Revised 2008). If 1-9 *E.coli* or total coliforms per 100 ml are recorded in the distribution zone then remedial action must be taken but a major transgression is not deemed to have occurred. Once, a result of ≥10 *E.coli* or total coliforms per 100 ml is recorded then a major transgression is deemed to have occurred and the drinking-water assessor must be notified immediately and remedial actions must be taken (MoH, 2008).

Although these categories have not been adopted in previous studies they do correlate with the reporting requirements of the DWSNZ 2005 (Revised 2008).

Appendix J. Statistical information for dwellings with a metered or a restrictor-only water supply

SPSS Version 20 was used to analyse the data in this study. Excel was then utilised to produce tables and graphs of the results of the analyses.

J.1 Analyses performed

Non-parametric tests were performed on the results from this survey as the data was not normally distributed. Analyses were performed on the results from metered dwellings and from restrictor-only dwellings: no analyses were performed on restrictor-supplemented supplies as the sample size was too small.

Chi squared goodness-of-fit tests were performed on categorical data to determine if there were any significant differences in the results obtained. When cell counts were less than five, categories were grouped to ensure cell counts were greater than five. When categories could not be grouped either the Fisher's exact test was used, instead of the chi squared test, or analyses were not performed. Mann-Whitney tests were performed when there was a categorical and a numerical variable. SPSS did not record a Mann-Whitney value, only a two-tailed significance level. Significance level for all tests was set at 0.05. Results of $p=0.000$ were recorded as $p<0.0005$ and results of $p=0.0000$ were recorded as $p<0.00005$.

J.2 Response rates.

Response rates were calculated by dividing the total number of people, with a particular dwelling type, that agreed to take part in the survey, by the number of people (with that dwelling type) that were asked to take part in the survey.

J.3 Water storage

Only limited analyses could be performed on data relating to water storage options employed by participants, as there were too few counts in each category recorded. These analyses have limited value as sample numbers were small. 'Don't know' responses were not included in these analyses. Total coliform counts were used for these analyses and results were placed into two groups: compliant with the DWSNZ 2005 (Revised 2008) or non-compliant with the DWSNZ 2005 (Revised 2008).

Appendix K. Tables of data for metered and restrictor-only dwellings

Table K1. Age in years for participants with a metered or a restrictor-only water supply.

(Data for Figure 7)

	Participants' age in years						
	15-19	**20-29**	**30 - 39**	**40 - 49**	**50 - 59**	**60+**	**Total**
Metered	0	0	2	14	11	22	49[a]
Restrictor-only	0	0	1	14	14	21	50

[a]does not sum to 50 as one participant did not respond to this question

Table K2. Ethnicity of participants with a metered or a restrictor-only water supply.

	Ethnicity			
	Maori	**European**	**Other**	**Total**
Metered	2	43	4	49[a]
Restrictor-only	0	47	3	50

[a]does not sum to 50 as one participant did not respond to this question

Table K3. Occupation of participants with a metered or a restrictor-only water supply

(Data for Figure 8)

	Occupation							
	Home executive	Retired	Professional	Community and personal service	Technicians and trade workers	Clerical and admin workers	Labourers	Total
Metered	4	17	13	4	7	2	3	50
Restrictor-only	5	14	22	6	2	1	0	50

Table K4. Length of time lived at dwelling for participants with a metered or a restrictor-only water supply

	Length of time				
	<1 year	1-5 years	6-10 years	>10 years	Total
Metered	5	15	8	21	49
Restrictor-only	6	9	16	19	50

Table K5. Dwelling ownership for participants with a metered or a restrictor-only water supply

	Dwelling ownership		
	Yes	No	Total
Metered	43	5	49[a]
Restrictor-only	49	1	50

[a]does not sum to 50 as one participant did not respond to this question

Table K6. Land area for participants with a metered or a restrictor-only water supply

	Area of land				
	<4,000m^2	4,000m^2 - 4 ha	4.1 ha - 8 ha	>8 ha	Total
Metered	47	2	0	0	49[a]
Restrictor-only	15	26	7	2	50

[a]does not sum to 50 as one participant did not respond to this question

Table K7. Number of persons living at each dwelling for dwellings with a metered or a restrictor-only water supply

(Data for Figure 9).

	Number of persons living at dwelling								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Metered	9	15	5	17	0	1	1	1	49[a]
Restrictor-only	1	29	5	10	4	1	0	0	50

[a]does not sum to 50 as one participant did not respond to this question

Table K8. Number of bedrooms for dwellings with a metered or a restrictor-only water supply

(Data for Figure 10)

	Number of bedrooms					
	1	**2**	**3**	**4**	**5**	**Total**
Metered	1	8	25	11	4	49[a]
Restrictor-only	0	1	13	27	9	50

[a]does not sum to 50 as one participant did not respond to this question

Table K9. Microbiological results for dwellings with a metered water supply

(Data for Figure 11 and Figure 12)

ID	Total coliforms per 100 ml	*E.coli* per 100 ml	ID	Total coliforms per 100 ml	*E.coli* per 100 ml
M4	<1	<1	**M35**	<1	<1
M6	<1	<1	**M36**	<1	<1
M8	<1	<1	**M37**	<1	<1
M9	<1	<1	**M38**	<1	<1
M11	<1	<1	**M39**	<1	<1
M13	<1	<1	**M40**	<1	<1
M14	<1	<1	**M41**	<1	<1
M15	<1	<1	**M42**	<1	<1
M16	<1	<1	**M43**	<1	<1
M18	<1	<1	**M44**	<1	<1
M19	<1	<1	**M45**	<1	<1
M20	<1	<1	**M46**	<1	<1
M21	<1	<1	**M47**	<1	<1
M22	<1	<1	**M48**	<1	<1
M23	<1	<1	**M49**	<1	<1
M24	<1	<1	**M50**	<1	<1
M25	<1	<1	**M51**	<1	<1
M26	<1	<1	**M1**	1.0	<1
M28	<1	<1	**M2**	1.0	<1
M29	<1	<1	**M5**	1.0	<1
M30	<1	<1	**M7**	1.0	<1
M31	<1	<1	**M12**	1.0	<1
M32	<1	<1	**M17**	1.0	<1
M33	<1	<1	**M27**	3.1	<1
M34	<1	<1	**M10**	4.1	<1

Table K10. Microbiological results for dwellings with a restrictor-only water supply

(Data for Figure 11 and Figure 12)

ID	Total coliforms per 100 ml	*E.coli* per 100 ml	ID	Total coliforms per 100 ml	*E.coli* per 100 ml
R1	<1	<1	**R57**	1.0	<1
R3	<1	<1	**R35**	2.0	<1
R4	<1	<1	**R16**	3.0	<1
R5	<1	<1	**R11**	3.1	<1
R6	<1	<1	**R10**	4.1	<1
R7	<1	<1	**R12**	4.1	<1
R9	<1	<1	**R21**	4.1	<1
R13	<1	<1	**R29**	5.1	<1
R15	<1	<1	**R39**	5.2	<1
R18	<1	<1	**R30**	7.4	<1
R19	<1	<1	**R40**	13.1	<1
R22	<1	<1	**R48**	16.0	<1
R25	<1	<1	**R46**	18.3	<1
R28	<1	<1	**R17**	20.1	1
R36	<1	<1	**R55**	24.3	<1
R41	<1	<1	**R26**	27.8	<1
R45	<1	<1	**R42**	32.7	<1
R47	<1	<1	**R33**	44.1	<1
R48	<1	<1	**R31**	66.3	<1
R53	<1	<1	**R51**	72.2	<1
R59	<1	<1	**R52**	98.7	<1
R60	<1	<1	**R2**	120.1	<1
R61	<1	<1	**R49**	157.6	4.1
R63	<1	<1	**R33**	261.3	<1
R44	1.0	1.0	**R56**	344.8	<1

Table K11. Reasons for not having water testing done for participants with a metered or a restrictor-only water supply

(Data for Figure 14)

	Reasons for not having water testing done					
	No reason/no need	**TDC supply and assume safe**	**No sickness**	**Hadn't thought about it**	**Other**	**Total**
Metered	29	8	4	6	3	50
Restrictor-only	20	8	6	5	4	43[a]

[a]does not sum to 50 as 7 participants have had their water tested

Table K12. Perception of taste of drinking-water for participants with a metered or a restrictor-only water supply

(Data for Figure 15)

	Perception of Taste					
	Very poor	**Poor**	**Average**	**Good**	**Very good**	**Total**
Metered	1	0	8	17	24	50
Restrictor-only	1	1	5	24	19	50

Table K13. Perception of odour of drinking-water for participants with a metered or a restrictor-only water supply

(Data for Figure 16)

	Perception of odour					
	Very poor	**Poor**	**Average**	**Good**	**Very good**	**Total**
Metered	1	1	7	26	15	50
Restrictor-only	1	0	5	29	15	50

Table K14. Perception of colour of drinking-water for participants with a metered or a restrictor-only water supply

(Data for Figure 17)

	Perception of colour					
	Very Poor	**Poor**	**Average**	**Good**	**Very good**	**Total**
Metered	0	0	6	27	17	50
Restrictor-only	0	0	3	30	17	50

Table K15. Perception of safety of drinking-water for participants with a metered or a restrictor-only water supply

(Data for Figure 18)

	Perception of safety						
	Very poor	Poor	Average	Good	Very good	Don't know	Total
Metered	0	0	2	33	11	4	50
Restrictor-only	1	1	5	29	12	2	50

Table K16. Perception of value for money of drinking-water for participants with a metered or a restrictor-only water supply

(Data for Figure 19)

	Value for money					
	Very poor	Poor	Average	Good	Very good	Total
Metered	6	13	9	20	2	50
Restrictor-only	5	9	10	23	3	50

Table K17. Knowledge of the treatment status of the Richmond water supply for participants with a metered or a restrictor-only water supply

(Data for Figure 20)

	Knowledge of treatment status of Richmond water supply			
	Treated	**Untreated**	**Don't know**	**Total**
Metered	19	3	28	50
Restrictor-only	26	7	17	50

Table K18. Number of water storage tanks owned by each participant with a restrictor-only water supply

(Data for Figure 21)

	Number of tanks per dwelling				
	1 tank	**2 tanks**	**3 tanks**	**4 tanks**	**Total**
Restrictor-only	41	7	1	1	50

Table K19. Capacity of each tank owned by participants with a restrictor-only water supply

(Data for Figure 22)

	Tank capacity							
	<5,000 L	5,001-10,000 L	10,001-15,000 L	15,001-20,000 L	20,001-25,000 L	>25,000 L	Don't know	Total
Number of tanks	5	1	2	3	26	6	19	62

Table K20. Total water storage capacity of tanks owned by participants with a restrictor-only water supply

	Total storage capacity				
	1,001 - 10,000 L	10,001 - 20,000 L	>20,000 L	Don't know	Total
Restrictor-only	3	4	31	12	50

Table K21. Age of each tank owned by participants with a restrictor-only water supply

(Data for Figure 23)

	Age of tank					
	<1 year	1-5 years	6-10 years	>10 years	Don't know	Total
Number of tanks	2	8	16	35	1	62

Table K22. Frequency of tank inspection by participants with a restrictor-only water supply

(Data for Figure 24)

	Frequency of tank inspection						
	Monthly	3 monthly	6 monthly	Yearly	>Yearly	Never	Total
Number of participants	5	1	5	9	18	24	62

Appendix L. Results and discussion for restrictor-supplemented supplies

L.1 Demographic details

There were four male and seven female participants with a restrictor-supplemented supply and they all identified with European ethnicity. Of the 11 participants, five were over 60 years of age, four were 50-59 years of age, and two were 40-49 years of age. Participants' occupation varied: five participants were home executives, two were retired, three were professional, and one was a community worker. All the participants with a restrictor-supplemented supply owned their own dwelling. Eight of the participants had lived at the dwelling for more than ten years, one had lived there for six to ten years, and two had lived there for one to five years. Eight dwellings were located on >4,000 m^2 and three dwellings were located on <4,000 m^2. The number of people living at each dwelling varied from one up to five people. Dwelling size varied from three bedrooms up to five bedrooms: three dwellings had three bedrooms, five dwellings had four bedrooms, and three dwellings had five bedrooms.

L.2 Type of supplementary supply

Of the 11 restrictor-supplemented supplies; nine participants supplemented their Richmond water supply with rainwater, one with spring water, and one with well water. The participants with rainwater and the participant with well water, as an extra drinking-water supply, supplemented their town drinking-water supply all year round. The participant with spring water, as an extra drinking-water supply, only used town drinking-water during the drier months (usually January and February) when the spring did not provide sufficient water for their needs.

L.3 Water usage

All participants with a restrictor-supplemented drinking-water supply brushed their teeth, prepared food, and drank their household water supply. Ten of the participants made ice with the water supply from the kitchen tap and one participant made ice using filtered water from the fridge-freezer.

L.4 Microbiological water test results

L.4.1 Total coliform and *E.coli* results

The total coliform and *E.coli* results for the restrictor-supplemented dwellings are shown in Table 9. Total coliforms ranged from <1 up to 1,553.1 total coliforms per 100 ml. *E.coli* counts ranged from <1 up to 261.3 *E.coli* per 100 ml.

L.4.2 Compliance with DWSNZ 2005 (Revised 2008)

The results in Table 9 show that three of the eleven dwellings complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of <1 total coliform per 100 ml. If using *E.coli* as a measure of compliance, instead of total coliforms, then five of the eleven dwellings complied with the microbiological criteria in the DWSNZ 2005 (Revised 2008) of <1 *E.coli* per 100 ml.

L.5 Water treatment devices installed

L.5.1 Number and type of water treatment devices installed

Four participants with a restrictor-supplemented supply had installed water treatment devices: two had fine filtration (<10 microns) with an ultraviolet light treatment device; one participant had fitted a five micron filter and one participant had a kitchen bench-top filter that she believed to be a fine filter (Table L1). The kitchen bench filter was a point-of-use device. The UV filtration systems and the five micron filter were fitted so that treated water was supplied to the whole house.

L.5.2 Reason for installation of water treatment device

All participants with a restrictor-supplemented supply had fitted their water treatment device to ensure that their drinking-water supply was safe to drink.

Table L1. Type of treatment device and results of water testing for dwellings with a restrictor-supplemented supply

				Untreated		Treated	
ID	**Type of supply**	**Type of treatment**	**Date fitted**	**Coliforms per 100 ml**	***E.coli* per 100 ml**	**Coliforms per 100 ml**	***E.coli* per 100 ml**
R20	Restrictor and rainwater	Fine filtration plus UV	1-2 yrs ago	N/A[a]	N/A[a]	<1	<1
R37	Restrictor and rainwater	Fine filtration plus UV	>5 yrs ago	N/A[a]	N/A[a]	<1	<1
R50	Restrictor and rainwater	5 micron filter	Don't know	N/A[a]	N/A[a]	124.6	6.3
R27	Restrictor and well water	Fine filtration	>5 yrs ago	866.4	261.3	206.3	110.6

[a] results not available for untreated water as treatment device was fitted so that treated water was supplied to the whole dwelling

L.5.3 Effectiveness of water treatment devices

Table L1 provides details of the effectiveness of the water treatment devices. The results show that the two dwellings with fine filtration (>10 microns) plus UV had <1 *E.coli* and <1 total coliform per 100 ml in their drinking-water. The dwelling with a five micron filter and the dwelling with a bench-top filter (believed to be a fine filtration device) still had contaminated drinking-water post-treatment.

These results confirm the existing information available on filtration systems which states that more advanced treatment systems, such as UV systems, are more effective at removing contamination than simpler treatment methods (MoH, 2005c). The results also confirm the advice given by the Ministry of Health that type of water treatment system employed should be matched to the levels of microbiological contamination present in the source water (MoH, 2005c) and to the requirements of the dwelling owner. Both the participants who had fitted a filtration system and still had contamination in their water supply were surprised to learn of the contamination, as they believed that the filter fitted would remove any contamination present. However, the filtration systems fitted were not adequate for the levels of contamination present in the source waters.

L.6 Water testing behaviour

L.6.1 Reasons for and frequency of water testing

Three participants with restrictor-supplemented supplies had had their drinking-water tested. This low level of testing behaviour is similar to that found in previous surveys on private water supplies (Jones et al., 2005, 2006). One participant (R37), with a rainwater supplemented supply, had their water tested for microbiological contamination by a water specialist prior to installing a fine filtration and UV water treatment device. Another participant (R50), with a rainwater-supplemented supply, had their drinking-water supply tested for *E.coli* and coliforms. After testing, a five micron filter was fitted in the supply system. The third participant (R27), who had water supplemented from a spring, had the drinking-water tested (about 15 years ago) for 'hardness – scale'. Although the water test result showed high levels of scale the participant decided to not treat the water as it was too expensive to fit a treatment system. Instead, the hot water element is replaced every 12-18 months.

L.6.2 Reasons for not water testing

The participants who had not had their water tested stated that they had not had their water tested because they either had ‘no concerns’ (4/11), they had ‘meant to but hadn’t got around to it’ (3/11), or they ‘believed the supply to be safe to drink’ (1/11). These reasons were similar to those given by participants with a restrictor-only supply but were different to those given in previous studies. In previous studies the main reasons given why participants did not have their water tested were ‘inconvenience and cost’ (Hexemer et al., 2008), ‘inconvenience’ and ‘lack of health problems’ (Jones et al., 2006).

L.7 Participants’ perceptions of drinking-water quality

L.7.1 Perception of taste, odour, and colour

Perceptions of taste, odour, and colour for participants with a restrictor-supplemented water supply can be seen in Figure L1. All participants rated the organoleptic properties of their drinking-water to be of average or above average quality.

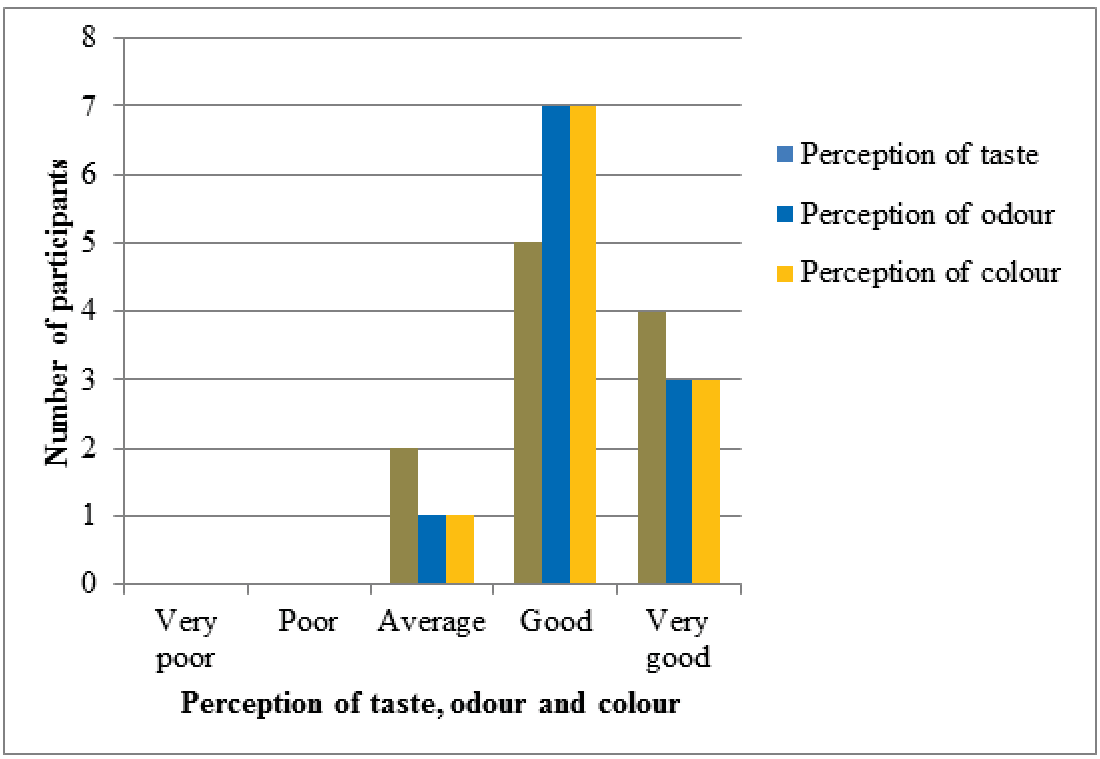

Figure L1. Perception of taste, odour, and colour of drinking-water for participants with a restrictor-supplemented drinking-water supply

It is evident from these results that the presence of contamination in a water supply does not necessarily affect a person’s perception of the safety or the organoleptic properties of a drinking-water supply, as participants with contamination in their supply still rated the safety and organoleptic properties of their drinking-water highly. This corroborates previous research which has shown that even when contamination is present consumers are still satisfied with their drinking-water supply (Schwartz et al., 1998).

L.7.2 Perception of safety and value for money

Participants' perceptions of safety and value for money are shown in Figure L2.

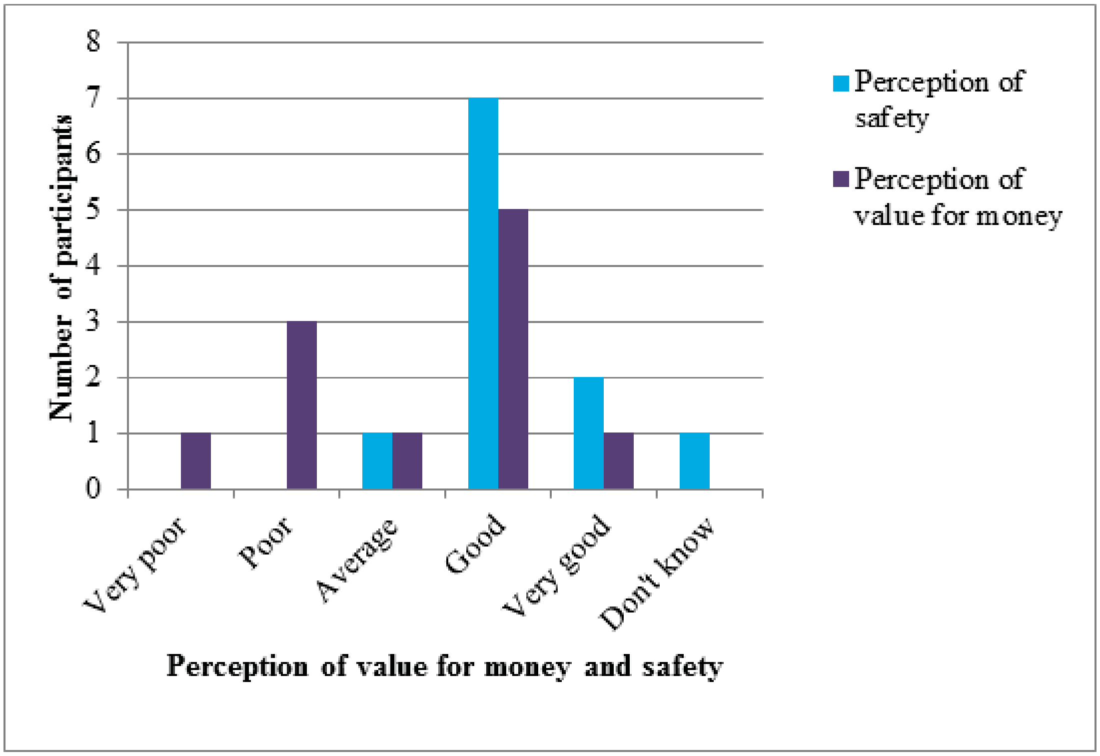

Figure L2. Perception of safety and value for money of drinking-water for participants with a restrictor-supplemented supply

Not all of the participants with a restrictor-supplemented supply rated their water supply as being above average in value for money as four participants believed the Richmond water supply to be either 'poor' or 'very poor' value for money. Participants mentioned that they were frustrated that they had to pay for a set amount of water each year from the Council even though they did not use the amount of water that they paid for. Participants felt that they did not have sufficient rainwater to manage without the Council supply and would have liked to have a metered system whereby they only paid for the water that they used.

L.8 Knowledge of the Richmond urban water supply

The knowledge status of participants with a restrictor-supplemented supply regarding the treatment status and grading of the Richmond supply was similar to those for participants with a restrictor-only supply. Of the 11 participants with a restrictor-supplemented supply; two participants knew the water supply was untreated, five believed it to be treated, and four participants did not know the water treatment status of the Richmond water supply. No participants with a restrictor-supplemented water supply knew the public health grading for the Richmond supply.

Four participants with a restrictor-supplemented supply had been to the Tasman District Council to inquire about their drinking-water supply. The other seven participants had not accessed any of the information sources stated in question Q6 of the questionnaire.

L.9 Water storage systems

There were a total of 18 tanks between the 11 dwellings: six dwellings had one water storage tank, four dwellings had two water storage tanks, and one dwelling had four water storage tanks. Eleven of the 18 water storage tanks were concrete, four were polyethylene, and three were fibreglass. Water storage capacity varied from 9,000 L up to 120,000 L. Six dwellings had a total water storage capacity in excess of 20,000 L, one dwelling had less than 10,000 L, and one dwelling had 10-20,000 L of water storage. Three participants did not know what water storage capacity they had. The capacity of each tank owned by participants with a restrictor-supplemented water supply is shown in Figure L3.

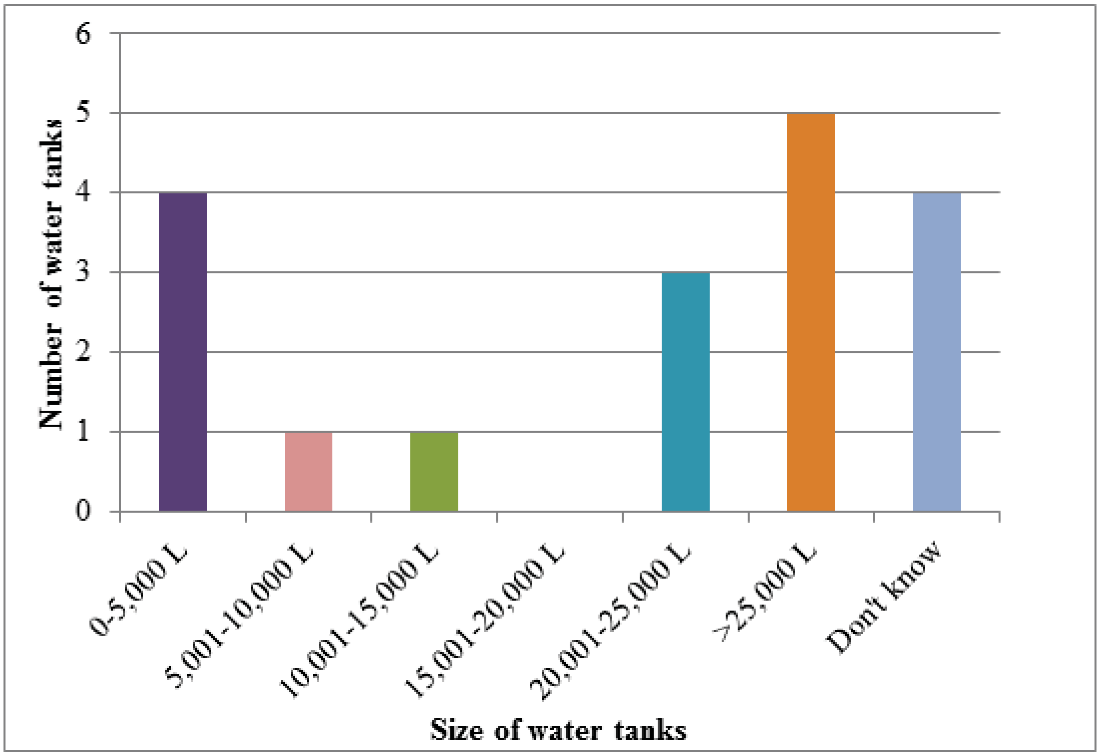

Figure L3. Capacities of water storage tanks owned by participants with a restrictor-supplemented drinking-water supply

Nine tanks were located on the ground and nine tanks were located below the ground. All nine tanks below ground were concrete tanks. Fourteen of the 18 water tanks were >10 years old, one tank was six to 10 years old, and three tanks were one to five years old. Participants stated that all tanks had lids and all lids were firmly in place. One participant with a rainwater supply had a tank vacuum system in the water storage tank, two participants had a tank screen mesh on their water tanks, and one participant had a water depth indicator. No tanks had air vents, a floating hose draw-off, a calmed inlet, or a tank sock.

For restrictor-supplemented supplies, most tanks were concrete (11/18) which differs to restrictor-only supplies were half of the tanks were concrete and half were polyethylene. Water storage capacity for restrictor-supplemented dwellings was also different to that for restrictor-only dwellings with restrictor-supplemented dwellings having a greater number of smaller tanks than restrictor-only dwellings (33.3% compared to 17.7% respectively). Tank age also varied between restrictor dwelling types with more restrictor-supplemented dwellings have a greater number of tanks that were >10 years old (14/18 tanks). Tank location was different for restrictor-supplemented dwellings as half of the tanks were above ground and half below ground. This compares to restrictor-only dwellings where most tanks were above ground (54/62).

Any of these differences in the storage systems between restrictor-only and restrictor-supplemented may have partially accounted for the increased levels of contamination present in the restrictor-supplemented supplies. Older tanks may not have been in as good a condition as new tanks and may have had more cracks and gaps in them that would have allowed the ingress of contaminants. Older tanks may have had a greater accumulation of sediment on the bottom which would provide an environment for the survival of microorganisms (Al-Bahry et al., 2011; Martel et al., 2002; Tokajian & Hashwa, 2004). Tank location might also have affected levels of contamination as tanks located below-ground are more susceptible to contamination from surface run-off, and the ingress of environmental or faecal contamination (Cunliffe, 1998). However, the most likely differences in contamination levels between restrictor-only dwellings and restrictor-supplemented dwellings were likely to be caused by supplementing the water supply with water from another source.

L.10 Maintenance of water supply systems

All four participants with a restrictor-supplemented water supply and a water treatment system carried out maintenance on their water treatment system. The two participants with a fine filtration and UV treatment system carried out maintenance on their water treatment unit twice a year: one participant carried out the maintenance himself, the other participant employed a service technician. The participant with a five micron filter changed the filter when the water flow to the house was reduced. The participant with a bench top filter had the filter serviced twice a year by a service technician.

The frequency with which water storage tanks were inspected by participants with a restrictor-supplemented water supply is shown in Figure L4. Inspection of water storage tanks was undertaken more often by participants with a restrictor-supplemented supply than with a restrictor-only supply. This was to be expected as participants with a restrictor-supplemented supply, supplemented with rainwater, stated that they often checked their water tanks to determine how much water was in the tank.

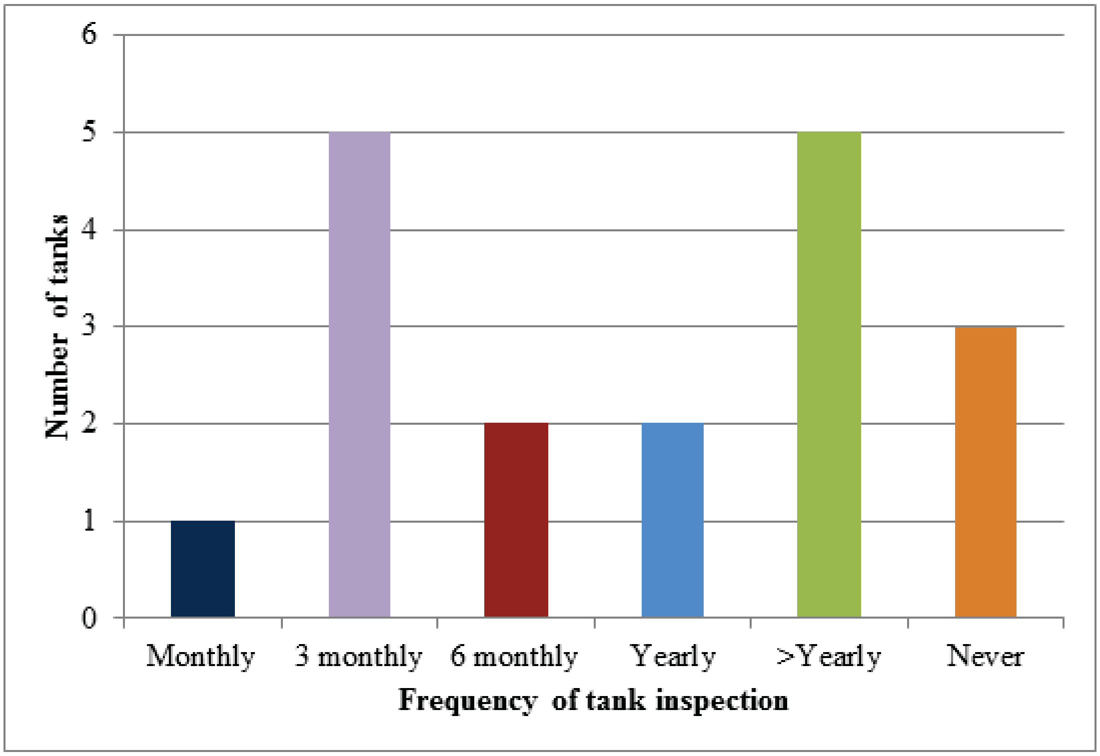

Figure L4. Frequency of water storage tank inspection by participants with a restrictor-supplemented water supply

Participants with a restrictor-supplemented supply seldom cleaned their water tanks with 15 out of the 18 tanks never having been cleaned. This result was similar to previous studies undertaken on owners of private water supplies which showed that owners of these supplies rarely cleaned their storage tanks (Abbott et al., 2006; Baguma et al., 2010; Thompson, 2011a; Verrinder & Keleher, 2001).

L.11 Restrictor supplies supplemented with rainwater

All nine dwellings with a town water supply, supplemented with rainwater, had roof-collected rainwater flowing into their tanks year round. Seven of these nine dwellings collected the rainwater from the dwelling roof and the other two properties collected the rainwater from the garage roof.

Roofing material for five dwellings was galvanised iron, for two dwellings was concrete tile, for one dwelling was colour steel, and for one dwelling was coated aluminium tile. Roof guttering for the nine dwellings also varied: seven dwellings had PVC roof guttering, one had galvanised iron, and one had anodised aluminium/copper. Three dwellings had gutter guard screens in their gutters, one dwelling had a leaf slide, and one dwelling had a tank rain-catcher filter.

Owners of roof-collected rainwater supplies are recommended to install simple physical measures, such as tank inlet screens and first flush diverters, to protect drinking-water quality (Abbott 2007, 2008; Ashworth, 2005; Cunliffe, 1998; MoH, 2005c). The use of these devices has been shown to reduce the levels of contamination present in the drinking-water supply (Kus, Kandasamy, Vigneswaran, & Shon, 2010). However, the results of this study have confirmed the results of previous studies which have shown that these devices are seldom employed by owners of private water supplies sourced from rainwater (Abbott et al., 2006; Rodrigo et al., 2010).

There were numerous trees overhanging the roofs of two dwellings. Four dwellings had no trees overhanging their roof, two dwellings had a few trees, and one dwelling had a moderate amount of trees overhanging the dwelling. The frequency of hearing or seeing birds or animals on the roof is shown in Table L2.

Table L2. Frequency of presence of birds and animals on the roof of dwellings with a restrictor supply supplemented with roof-collected rainwater

	Frequency of presence on roof			
	Never	**A few times**	**Very often**	**Unsure**
Birds	0	5	0	1
Animals	3	1	0	4

The roofs of five dwellings, with a roof-collected rainwater supply, were never cleaned and the other four roofs were only cleaned occasionally by the participant or family member of the participant. Gutters were cleaned more often than roofs with two dwellings having their gutters cleaned every three months, one dwelling every six months, three dwellings annually, and two dwellings occasionally. Gutters were cleaned by the participant or by a family member of the participant. One participant never cleaned the gutters.

Maintenance and cleaning of roofs and guttering are essential for maintaining the microbiological quality of a roof-collected water supply (Abbott, 2007, 2008; Cunliffe, 1998; MoH, 2005c). Participants in this study mentioned that they had trees overhanging their roofs, and were aware of the presence of birds and animals on their roofs. If roofs and gutters are not regularly cleaned leaves from these trees and faecal matter from the birds and animals present on the roofs can enter and contaminate the drinking-water supply.

L.12 Restrictor supply supplemented with spring water

The participant with a supply supplemented with spring water only used the town water supply when the spring ran dry, usually in the summer months. The spring was situated in grazed pasture 250 m up the hill from the main dwelling. The spring had flow all year round and it provided approximately 8,000 litres per day of water in winter and 1,500 litres per day in summer. The spring had a concrete liner that was 2 m deep and it had a concrete lid. There was an electric fence that kept stock at least 3 m from the spring. However, the participant mentioned that stock used a resting pad located 10 m above the spring. The participant checked the fencing around the spring annually. When necessary the spring was inspected and the pipes were bled. The water test results for this dwelling showed 43.4 total coliforms per 100 ml and one *E.coli* per 100 ml.

L.13 Restrictor supply supplemented with well water

The participant with a water supply supplemented with well water supplemented their town water supply with water from the well all year round. The well was situated behind the main dwelling and was approximately 10 m deep. The well was dug more than 10 years ago. Water was pumped from the well, through concrete pipes, to the water storage tank. After rain the water in the well becomes very discoloured as an underground stream feeds into the well. The paddocks above the well were heavily grazed by both sheep and cattle and these animals had access to the stream where it flowed above ground. Maintenance on the well was undertaken as required. A bench top filtration system had been fitted in the kitchen. The participant believed that this filter tap was providing a source of 'safe' drinking-water. The water test results for this dwelling showed 866.4 total coliforms per 100 ml and 261.3 *E.coli* per 100 ml from the kitchen tap. The water sample from the filter tap showed 206.3 total coliforms per 100 ml and 110.6 *E.coli* per 100 ml.

The owner of this dwelling was distressed by these results as she had been led to believe that the bench-top filtration device would provide a potable supply of water. Her distress was partially caused by concern for her 18 month old grandson who had been sick with gastroenteritis since staying at her dwelling a month previously. He had consumed baby formula made with water from the filter tap that had been warmed, not boiled. Her grandson had been tested for Giardia and returned a negative result but the owner was still concerned that the drinking-water from her dwelling may have been the cause of the gastroenteritis. The owner now understands that her filtration system reduces the levels of contamination but does not remove all contamination present in her drinking-water supply. All water consumed at this dwelling is now boiled prior to use.

Appendix M. Tables of data for restrictor-supplemented dwellings

Table M1. Perceptions of participants with a restrictor-supplemented drinking-water supply

(Data for Figure L1 and Figure L2)

	Perception of water supply						
	Very poor	**Poor**	**Average**	**Good**	**Very good**	**Don't know**	**Total**
Perception of taste	0	0	2	5	4	0	11
Perception of odour	0	0	1	7	3	0	11
Perception of colour	0	0	1	7	3	0	11
Perception of safety	0	0	1	7	2	1	11
Perception of value for money	1	3	1	5	1	0	11

Table M2. Capacities of water storage tanks owned by participants with restrictor-supplemented water supplies

(Data for Figure L3**)**

	Water storage tank capacity in litres							
	0-5,000 L	**5,001-10,000 L**	**10,001-15,000 L**	**15,001-20,000 L**	**20,001-25,000 L**	**>25,000 L**	**Don't know**	**Total**
Number of tanks	4	1	1	0	3	5	4	18

Table M3. Frequency of inspection of water storage tanks owned by participants with a restrictor-supplemented water supply

(Data for Figure L4)

	Frequency of inspection						
	Monthly	3 monthly	6 monthly	Yearly	>Yearly	Never	Total
Number of participants	1	5	2	2	5	3	18