The microbiological quality of roof-collected rainwater of private dwellings in New Zealand

S. Abbott[1] , B. Caughley[1] & J. Douwes[2].
[1]Institute of Food Nutrition and Human Health, Massey University, New Zealand
[2]Centre for Public Health Research, Massey University, New Zealand
[1]Email: S.E.Abbott@massey.ac.nz

ABSTRACT

In this 5 - year study we investigated the microbiological quality of roof-collected rainwater samples of 560 private dwellings in New Zealand. At least half of the samples analysed exceeded the minimal acceptable standards for contamination and 41% of the samples showed evidence of heavy faecal contamination. The likely sources of the faecal contamination were faecal material deposited by birds, frogs, rodents and possums, and dead animals and insects, either on the roofs or in the gutters, or in the water tank itself. Many of the roof water supplies surveyed revealed deficiencies in the use of rainwater catchment systems and components. In a significant number of supplies where we found heavy faecal contamination there was evidence of lack of maintenance; inadequate disinfection of the water; poorly designed delivery systems and storage tanks; and failure to adopt physical measures to safeguard the water against microbiological contamination.

The results of this study indicate that the information on the safe collection and storage of roof-collected rainwater seems not to be reaching many users in New Zealand. Roof water users need more information pertaining to their roof water supplies but we believe improvements are necessary in the dissemination of this information.

INTRODUCTION

In New Zealand more than 10% of the population depends on roof-collected rainwater systems for their drinking water - especially in rural areas that are not served by municipal town water supplies. Roof-collected rainwater consumption is also popular because the general public has the perception that rainwater is "pure" and safe to drink. Indeed, the risk of disease arising from roof-collected rainwater consumption can be low, providing that the water is visibly clear, has little taste or smell and, most importantly, the storage and collection of rainwater is via a properly maintained tank and roof catchment system. The microbiological quality of stored roof-collected rainwater can be impacted directly by roof catchment and subsequent run-off contamination, via direct depositions by birds and small mammals, decay of accumulated organic debris, and deposition of airborne micro-organisms.

Several overseas investigations in the 1980s raised concerns when they revealed that in many instances stored rainwater did not meet WHO, EPA or other similar standards with respect to one or more bacteriological water quality indicators (Fujioka & Chinn, 1987; Haebler & Waller, 1987; Krishna, 1989). In northeast Thailand, where several million people use rainwater tanks, a major study of rainwater quality by Wirojanagud *et al.* (1989) on 189 rainwater storage tanks, revealed that only around 40% met WHO drinking water standards. The results of the indicator organism counts from the water samples from roofs and gutters indicated that the faecal contamination was from non-human sources such as animals, birds and rodents.

An individual household drinking water supply is a stand-alone system that is not connected to a community drinking water supply. While the *Drinking Water Standards for New Zealand (DWSNZ 2005*) do not require an individual household to demonstrate ongoing compliance, the owner still has a responsibility to produce safe (potable) drinking water. In New Zealand, statutory control of individual water supplies falls under the *Health Act* 1956, the *Local Government Act* 2002, and the *Building Act* 2004. The *Building Act* requires premises to be provided with potable water for consumption, oral hygiene, utensil washing and food preparation. Under Section 39 of the *Health Act* it is illegal to let or sell a house unless there is a supply of potable water.

In this study we collected and analysed 560 roof water samples from private (unregistered) dwellings in New Zealand in order to establish the levels of contamination and also to determine the most likely reasons for the contamination.

METHODOLOGY

Sample collection:

Most of the samples for this study were collected from private dwellings in the lower half of the North Island although some samples were also collected from dwellings in rural Dunedin and Waiheke Island. At the time of sampling residents were asked to complete a questionnaire about their drinking water system including details about what measures they took to safeguard their water supply from contamination.

Kitchen tap water samples were collected aseptically in sterile 250 ml plastic bottles. The samples were placed on ice packs in a chilly bin and transported to the laboratory, usually within 12 hours, and processed within 6 hours of arrival in the laboratory.

Analysis of samples:

All the samples were analysed for *Total coliforms* and *Escherichia coli* using the Colilert™ Quanti-Tray system (IDEXX Laboratories, Westbrook, Maine, United States). The procedure was performed according to the manufacturer's instructions using aseptic techniques and control cultures were put up at regular intervals throughout the study. *Klebsiella pneumoniae* was used as a partial positive control, *Escherichia coli* as a complete positive control, and *Pseudomonas aeruginosa* was used as a negative control.

Reporting of the results to participants:

All residents were sent a laboratory report, usually within 5 days of the analysis of their water sample, containing the results together with our interpretation of the meaning of the results. *Total coliforms* were indicative of environmental contamination (e.g.soil and vegetation) and *Escherichia coli* indicative of faecal contamination.

Only samples that yielded zero *total coliforms* and zero *E.coli* per 100 ml were considered to be uncontaminated. This is in keeping with the *DWSNZ 2005* which states that "………individual supplies that serve less than 1500 person days (e.g. less than 25 people for 60 days) each year are exempt from having to demonstrate ongoing compliance with the *DWSNZ 2005* but must have safe (potable) water". This means that the drinking water must not contain any contaminants that exceed the maximum acceptable values (MAVs), which in the case of *Total coliforms* and / or *E.coli* is less than 1 organism per 100ml (MOH, 2005).

With all report forms showing contamination, regardless of the degree of contamination, we included a Ministry of Health booklet *Household water supplies: the selection, operation, and maintenance of individual household supplies* – (Code 4602; 1999/2004) and the brochure *Water collection tanks and safe household water* – (Code 10148; 1999/2006). In samples where we found evidence of very heavy environmental and faecal contamination we recommended that the householders contact their local health protection or environmental health officer for advice and assistance on measures that needed to be implemented to safeguard the householder's water supply from contamination.

RESULTS

Roof water quality compliance monitoring:
As mentioned above we regarded samples as being uncontaminated only if *total coliforms* and *E.coli* were absent in the samples and this was conveyed to all participants. However, since some level of contamination of stored roof-collected rainwater is almost inevitable, for the overall compliance testing of all the samples in this study, we chose a somewhat arbitrary cut off point of 60 organisms per 100 ml for either *total coliforms* or *E.coli* to determine compliance.

We regarded counts of less than 60 organisms per 100 ml as still contaminated but "acceptable" so that 47% of samples were found to be "acceptable" for *total coliforms* and 59% of samples as "acceptable" for *E.coli* (Table 1).

Counts of greater than 60 organisms per 100 ml were regarded as heavily contaminated and therefore non-compliant. In other words 53% of samples were non-compliant and exceeded the 60 organisms per 100 ml level for *total coliforms*. Forty one percent of the samples exceeded the 60 organisms per 100 ml level for *E.coli*, indicating heavy faecal contamination of the water samples (Table 1). The likely sources of the faecal contamination were faecal material deposited by birds, frogs, rodents and possums, and dead animals and insects, either on the roofs or in the gutters, or in the water tank itself.

If we had used the *Drinking Water Standards for New Zealand (DWSNZ 2005*) instead for the compliance testing exercise detailed above then 70% of the roof-collected rainwater samples in this study would have been found to be non-compliant.

Range per 100ml (*N* = 560)	**Total coliforms** (per 100 ml)	**(*Escherichia coli*)** (per 100 ml)
0 - 10	179 (32%)	202 (36%)
10 – 20	34 (6%)	56 (10%)
20 – 60	50 (9%)	72 (13%)
60 – 100	67 (12%)	84 (15%)
100 – 200	62 (11%)	90 (16%)
>200	168 (30%)	56 (10%)

Table 1: Roof water quality of private dwellings in New Zealand

In this study we found no correlation between *total coliforms* and *E.coli.* While in some samples we did indeed find high levels of *total coliforms* as well as *E.coli*, in a significant number of samples with high *total coliforms* the *E.coli* count was low or even zero.

Gutter and tank cleaning:
Many of the roof water supplies surveyed revealed deficiencies in the use of rainwater catchment systems and components. In a significant number of supplies where we found heavy faecal contamination there was evidence of lack of maintenance (Tables 2 and 3).

3%	Didn't know
10%	No cleaning
18%	3 monthly
1%	6 monthly
33%	Yearly
15%	2 yearly
20%	Periodically

Table 2: Gutter cleaning

18%	Didn't know
30%	No cleaning
0%	3 monthly
0%	6 monthly
16%	Yearly
21%	2 yearly
15%	Periodically

Table 3: Tank cleaning

Measures to reduce contamination:
We also found that more than 50% of the householders did not have even simple physical measures in place to safeguard the water against microbiological contamination (Table 4). While 32% of the households did have down-pipe debris screens in place, a number of these were inaccessible for maintenance and cleaning and in some we observed bird's nests.

Didn't know	7%
None	52%
Gutter guards / screens	15%
First flush diverters	6%
Down-pipe debri screens	32%
Tank inlet screens / mesh	13%
Tank Raincatcher filter	1%
Sludge trap	3%
Tank Vac system	3%
Tank vacuum kit	1%
Floating valve out-take	1%

Table 4: Physical measures to reduce contamination.

Didn't know	4%
No treatment	61%
Chlorine	5%
Hydrogen peroxide	4%
Filtration	10%
Ultra violet radiation (UV)	2%
Filtration and UV	8%
Ozone	3%
Boiling	5%

Table 5: Water treatment

In very few of the private roof water dwellings that we surveyed was there evidence of any water treatment (Table 5). While 10% filtered the water we found that 71% of the filtered samples were in fact contaminated.

DISCUSSION

Maintenance and measures to prevent contamination:
These results are in keeping with results of similar but smaller New Zealand studies and highlight the fact that many rainwater supplies in this country are inappropriately designed and/or managed and suggest that information regarding safe rainwater collection and storage may not be getting through to the users (Fleming 2000; Simmons *et al.* 2000). Although a variety of methods are available for improving rainwater quality, Gould and Nissen-Petersen (1999) suggests that a good system design that is properly operated and maintained is the

simplest and most effective means of ensuring good water quality. In a study on the performance of rainwater tanks in New South Wales, Coombes *et al.*(2004) stated that kitchen water use (including drinking) is an insignificant portion (5%) of household water demand and this could be easily treated separately by methods such as filtration or boiling (Cunliffe 2004). Spinks *et al.*(2003) established that the rainwater treatment train, including the roof, tanks, pump and hot water service can remove the majority of contaminants from rainwater. These researchers believe that processes such as flocculation, settlement and bio-reaction processes improve the quality of rainwater.

Yaziz *et al.* (1989) has shown that the rainfall intensity and the number of days preceding a rainfall event significantly influence the quality of run-off water from the catchment systems. These researchers demonstrated that the longer the dry period between rainfall events, the greater the amount of pollutants deposited on the roof surfaces. Furthermore, rainfall intensity was shown to affect the quality of the run-off i.e. the wash-out process occurs faster for a particular roof surface with increases in the rainfall intensity. This reduces the foul flush volume so that the water may be collected and stored after a shorter “cleansing period”. The researchers also found that although no faecal coliforms were detectable after the fifth litre (a minimum foul flush volume of 5 litres was suggested), the presence of high levels of total coliforms and heterotrophic organisms indicate that caution is needed when selecting suitable foul flush volumes before capturing the run-off water for storage. A study by Coombes *et al.* (2000) revealed that in rainwater tanks, the highest counts occurred immediately after major rainfall events (≥ 50 mm) which washed organic material from the roof gutters into the tanks despite the presence of sophisticated first foul flush diverters. Nevertheless, the authors demonstrated a marked reduction in the bacterial counts over time suggesting that the rainwater tanks have a self-disinfection action.

While there is no clear evidence to suggest that bacterial growth can occur in visibly clean drinking water, Ahmed *et al.* (1998) found evidence of bacterial growth on the internal surfaces at the base of storage tanks and suggests that sedimentation of small amounts of organic matter entering the tanks could lead to a build-up of nutrients in the bottom of the storage tanks. Bacterial growth may occur when water in rainwater storage tanks is physically “dirty” and the bacteria have sufficient nutrients to multiply in the tanks. This is especially significant in countries with warm climates since many pathogenic bacteria require high ambient temperatures for regrowth. Regrowth of *E.coli* in water can be associated with rotting vegetation at elevated temperatures (Taylor, 1972). Results from a recent study involving the analysis of direct roof run-off at an urban housing development in Newcastle, Australia, indicated that airborne microorganisms represented a significant contribution to the bacterial load of roof water (Evans *et al.* 2006). This study suggests that airborne environmental organisms are likely to be important to the processes occurring within the storage tank such as competitive exclusion of pathogens, biofilm formation, and nutrient cycling.

Roof-collected rainwater consumption and health:

As we have shown in this survey, the quality of roof-collected rainwater is often very poor with high levels of faecal contamination in a significant number of the 560 samples that we analysed. However, we have as yet, not established the extent of gastrointestinal disease in New Zealand caused by the consumption of contaminated roof water. The health risks associated with non-compliant roof-collected rainwater consumption are not well defined or quantified because of many confounding factors associated with rainwater use. While relatively few disease outbreaks linked to contaminated roof-collected rainwater have been reported in New Zealand and overseas, the indications are that there could be under-reporting of illnesses associated with contaminated roof water. The lack of reports linking communicable disease outbreaks to roof-collected rainwater may in part be due to the fact that while rainwater use is extensive, most systems serve individual households of only a few persons. Therefore, residents experiencing sporadic gastrointestinal illnesses are less likely to seek medical attention unless the illnesses are severe and/or life-threatening. Furthermore, contaminated rainwater is more likely to be a source of sporadic disease episodes in these households because of possible immunity in a proportion of those exposed, and asymptomatic infection in others. Visitors or persons who have not consumed roof-collected rainwater previously could be especially at risk from waterborne diseases if the water supply is contaminated with pathogenic organisms (Simmons *et al.* 2001).

Moe *et al.* (1991) showed that the incidence of diarrhoea in young children was significantly related to drinking water containing high levels of bacterial contamination (>1000 *E.coli* per 100 ml) but little difference was observed between illness rates of children using either good quality drinking water (<1 *E.coli* per 100 ml) or moderately contaminated drinking water (2-100 *E.coli* per 100 ml). However, as shown by Morris (2003), the minimum infective dose of an organism varies widely depending not only the particular pathogen but also on the susceptibility of the host, the route of infection and environmental factors. Therefore, infective doses must be viewed with caution and cannot be directly used to assess risk.

Krishna (1993) formally proposed bacteriological water quality standards for potable rainwater that was considered to be achievable and less stringent than mains water standards. Faecal coliforms were proposed as the most appropriate indicator of tank water quality and a three-tier classification was suggested as a useful guide to tank water quality ranging from satisfactory (0 per 100 ml) to unsatisfactory (>10 per 100 ml). Recently however, Evans *et al.* (2007) questioned the relevance of faecal indicator organisms and suggested the need for a broader approach to the assessment of tank water quality, especially the likely role of environmental organisms in regulating tank water quality. Although the coliform group of organisms have been used as indicators for almost 100 years, research is ongoing to find better ways to assess the microbiological quality of drinking water, including new detection methodologies such as molecular techniques (Yates 2007).

CONCLUSION

At least 50% of the roof-collected rainwater samples from private dwellings exceeded the minimal acceptable New Zealand standards for contamination and 41% of the samples showed evidence of heavy faecal contamination. The likely sources of the faecal contamination were faecal material deposited by birds, frogs, rodents and possums, and dead animals and insects, either on the roofs or in the gutters, or in the water tank itself. Many of the roof water supplies surveyed revealed deficiencies in the use of rainwater catchment systems and components. In a significant number of supplies where we found heavy faecal contamination there was evidence of lack of maintenance; inadequate treatment of the water; poorly designed delivery systems and storage tanks; and failure to adopt even simple physical measures to safeguard the water against microbiological contamination.

Many of the organisms that have been isolated from contaminated roof water have the potential for human pathogenicity, which under certain conditions can lead to infection and possibly disease outbreaks, notably gastrointestinal diseases from pathogens such *Salmonella*, *Campylobacter*, *Giardia* and *Cryptosporidium*. While there will always be some risk of gastrointestinal illnesses to the consumers from supplies that are contaminated, the risk can be minimised by sensible preventative management procedures. Some of the preventative measures are associated with design and installation while others are associated with ongoing maintenance. Well designed systems are low maintenance and will generally prevent problems occurring so that corrective action to restore safe rainwater quality will be needed infrequently.

Information on the safe collection and storage of roof-collected rainwater seems not to be reaching many users in New Zealand. Accurate communication of the health risks of contaminated roof water is necessary so that the consumers can manage the risks. Roof water users by and large want and need more information pertaining to their private drinking water supplies but we believe that improvements are necessary in the dissemination of this information by health professionals. Observed differences in the perceptions and needs of residents on roof water supplies and between different age groups may indicate the need for targeted public health strategies

Changing the behaviour of consumers of roof-collected rainwater is not always easy. Any expected behavioural changes by roof-collected rainwater consumers will usually only be effective if it involves very little extra effort and cost to them. Behavioural changes will only occur if the public health messages to them are forthright and based on sound evidence.

ACKNOWLEDGEMENTS

The authors would like to thank the assistance provided by Heather Duckett, Elizabeth Harding, Amanda Eng, Soo Cheng and Alice Harding. The authors also gratefully acknowledge the funding provided by the New Zealand Ministry of Health and the Massey University Strategic Research Fund.

References:

Ahmed, S.A., Hoque, B.A. and A. Mahmud. (1998). Water management practices in rural and urban homes: a case study from Bangladesh on ingestion of polluted water. *Public Health.* ***112****; 317-312*

Coombes, P., Argue, J. and G. Kuczera. (2000). Rainwater quality from roofs, tanks and hot water systems at Fig Tree Place. *Third International Hydrological and Water Resources Symposium, Perth, 2000. 1042-1047.*

Coombes, P., Spinks, A., Evans, C. and H. Dunstan. (2004). Performance of rainwater tanks at an inner city house in Carrington NSW during drought. *WSUD. 504-515.*

Cunliffe, D. A. (2004). Guidance on the use of rainwater tanks. EN Health Council. *Department of Health and Ageing. Australian Government.*

Evans, C.A., Coombes, P.J. and R.H. Dunstan. (2006). Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater. *Water Research.* ***40****; 37-44.*

Evans, C.A., Coombes, P.J., Dunstan, R.H. and T. Harrison (2007). Identifying the major influences on the microbiological composition of roof harvested rainwater and the implications for water quality. *Water Science & Technology.* ***55****; 245-253.*

Fleming, J. (2000). Risk perception and domestic roof-collected rainwater supplies. *Master of Public Health Thesis. Auckland University, New Zealand.*

Fujioka, R.S. and R.D. Chinn. (1987). The microbiological quality of cistern waters in Hawaii. *Proceedings of the 3rd International Conference on Rain Water Cistern Systems, KhonKaen University, Thailand.* ***F3****;1-13*

Gould, J. and E. Nissen-Petersen. (1999). Rainwater catchment systems for domestic supply: design, construction and implementation. *Intermediate Technology Publications Ltd. London.*

Haebler, R. and D.Waller. (1987). Water quality of rainwater collection systems in the Eastern Caribbean. *Proceedings of the 3rd International Conference on Rain Water Cistern Systems, KhonKaen University, Thailand. 1-16*

Krishna, J. (1989). Cistern water systems in the U.S. Virgin Islands. *Proceedings of the 4th International Conference on Rain Water Cistern Systems, Manilla, Phillipines.* ***E2****;1-11*

Moe, C.L., Sobsey, M.D., Samsa, G.P. and V. Mesolo. (1991). Bacterial indicators of risk of diarrhoeal diseases from drinking water in the Philippines. *Bulletin of the World Health Oragainzation.* ***69****; 305-317.*

MOH. (2005a). Drinking-water standards for New Zealand 2005. *Ministry of Health. Wellington. New Zealand.*

Morris, R. (2003). Microorganisms and disease. *In*: Mara D. and N. Horan. *ed. The handbook of Water and Wastewater Microbiology. Academic Press. London. Pp. 177-183.*

Simmons, G., Gould, J., Gao, W., Whitmore, J., Hope, V. and G. Lewis. (2000). The design, operation and security of domestic roof-collected rainwater in rural Auckland. *Proceedings of the Water 2000 Conference 'guarding the global resource' New Zealand Water and Wastes Association. Auckland.* **Session 3***; Pp 1-16.*

Simmons, G., Heyworth, J. and M. Rimajova. (2001). Assessing the microbial health risks of tank rainwater used for drinking water. *Environmental Health.* ***3****; 57-64.*

Spinks, A., Coombes, P.J., Dunstan, R.H. and G. Kuczera. (2003). Water quality treatment processes in domestic rainwater harvesting systems. *28th International Hydrology and Water Resources Symposium. Wollongong.*

Taylor, E.W. (1972). Report on the results of the bacteriological, chemical and biological examination of London waters, 1969-1970. *Report of the Metropolitan Water Board.* ***44****; 22.*

Wirojanagud, W., Hovichitr, P. and P.Mungkarndee. (1989). Evaluation of rainwater quality: heavy metals and pathogens. *IDRC, Ottawa. 103p.*

Yates, M. V. (2007). Classical indicators in the 21st Century-far and beyond the coliform. *Water Environment Research.* **79**; 279-286.

Yaziz, M.I., Gunting, H., Sapari, N. and A. W. Ghazali. (1989). Variations in rainwater quality from roof catchments. *Water Research.* ***23****; 761-765.*