# An evaluation of measures for improving the quality of roof-collected rainwater

***S. Abbott***[1] , B. Caughley[1] A. Ward[1], G. Gowan[1] & J. Ashworth[2]
[1]Roof Water Research Centre, Massey University, New Zealand
[2]Opus International Consultants, Auckland, New Zealand
[1]Email: S.E.Abbott@massey.ac.nz

## ABSTRACT

Rainwater itself is free from pathogens and contamination levels of stored rainwater are generally low if tanks are well protected with covers or lids but obvious sources of contamination of the rainwater runoff can originate from faecal matter deposited by birds, frogs, possums, rodents, and dead animals and insects, either on the roofs or in the gutters, or in the water tank itself. A number of national and international studies have shown that the microbiological quality of roof-collected rainwater is usually poor, often fails to meet drinking water standards, and frequently there is evidence of faecal contamination in the stored roof water. In a significant number of roof water supplies of private dwellings in New Zealand where we found heavy faecal contamination, there was evidence of poorly designed delivery systems and storage tanks, and failure to adopt physical measures to safeguard the water against microbiological contamination.

A variety of low maintenance products and systems are now available in New Zealand for reducing, and in some situations even eliminating, microbial contamination of stored rainwater. In this paper we present the results of a preliminary study in which we evaluated the effectiveness of some of these products and systems. The study involved an intensive microbiological analysis of roof-collected rainwater samples collected over nine months and covered a range of climatic conditions.

## INTRODUCTION

The organisms isolated from contaminated roof water have the potential for human pathogenicity, which under certain conditions can lead to gastrointestinal diseases from pathogens such as *Salmonella*, *Campylobacter*, *Giardia* and *Cryptosporidium* (Simmons *et al.* 2001; Abbott *et al.* 2004). In a recent study on 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 30% of the samples showed evidence of heavy faecal contamination (Abbott *et al.* 2006). 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 heavy faecal contamination was found 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. Other similar but smaller New Zealand studies highlight the fact that numerous 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)

A variety of products and systems are now available in New Zealand for reducing, and in some situations eliminating, microbial contamination of stored roof-collected rainwater. In this stage one study we evaluated some of these products and systems in order to determine

their effectiveness in safeguarding roof-collected rainwater against contamination. The products and systems evaluated were:

- Calmed inlet pipes that allow the water to enter near the bottom of the tank without disturbing the sediment.
- Floating out-take systems suspended just below the surface of the water in the tank so that the cleanest water is drawn from the top of the tank.
- Tank vacuum systems that automatically siphon the sediment off the bottom of the tank when the tank overflows.
- First flush diverters that divert contaminated water away from the tank.
- A two tank in-series linked system that allows the cleanest water to be extracted for use from the second tank.

The preliminary study involved an extensive microbiological analysis of roof-collected rainwater samples and an examination of the influence of weather patterns on the bacterial loading of stored rainwater.

## METHODOLOGY

***Site location and roof catchment:***

This study was carried out at the Roof Water Research Centre (RWRC) at Massey University in Wellington. The RWRC is situated approximately 3 km from the centre of Wellington city and is positioned 30 metres from a major arterial road and is adjacent to 2 bus stops. The catchment surface of the RWRC comprises a galvanised iron roof and copper and PVC gutters with a roof area of approximately 200 $m^2$ consisting, on one level, of north and south panels and at a lower level, a smaller west facing panel. While the entire roof area is free of overhanging trees, there are a number of pine and pohutukawa trees surrounding the centre.

***Plumbing, storage tanks, and accessories:***

Roof top rainwater is harvested from the north and south panels via copper gutters into two 80 mm diameter PVC down-pipes that distribute the water onto the lower west roof panel through eight equally spaced horizontal 80 mm diameter spreader pipes. The rainwater from this west panel then runs into another 150 mm half-round PVC gutter that feeds two 100 mm PVC down-pipes for the supply of roof water to six polyethylene storage tanks. The down-pipes, each containing two debris screens (0.95 mm stainless steel mesh) drop down into two 100 mm diameter pipes that split into 3 equal 80 mm outlets, each containing its own isolator valve so that the roof–collected rainwater can be diverted to any tank individually or simultaneously to all six tanks. Water inlet pipes (80 mm diameter) to five of the six tanks are located at the top of the tank but in one tank (No. 3), the water enters the storage tank via a calmed inlet located at the bottom of the tank so as not to disturb any sediment that may accumulate in the bottom of this tank.

Each tank has a 50 mm PVC vent cowl with a light-proof cover allowing the flow of fresh air into the tanks and reducing the possibility of pressure build up. All of the tanks are also fitted with water level indicators (flagged-topped sliding rods on polystyrene floats) and also contain Minisonde 5A multiprobes (Hydrolab) with sensors for temperature, pH, conductivity, turbidity, dissolved oxygen, and ORP, LDO measurements. Each of the six tanks is fitted from top to bottom with 4 equally spaced sampling taps.

Other details of the RWRC tank configurations and systems are:

- Tank 1: A 25,000 litre tank containing a Tank Vacuum (Marley NZ) - bottom overflow - system designed to automatically vacuum the sediment off the bottom of the tank in the area of the out-take pipe every time the tank overflows. The bottom of the 90 mm vacuum pipe is attached to a notched coupling with 30 mm serrations where it sits on the tank floor.
- Tank 2: A 25,000 litre tank containing a TankVac (Tank Vac NZ) - bottom overflow - system also designed to automatically vacuum the sediment off the bottom of the tank when the tank overflows. An 80 mm vacuum pipe is connected to a magnetic valve 200 mm down from the top of the tank and the bottom of the vacuum pipe is attached to a tree of pipes across the floor of the tank.
- Tank 3: A 5,000 litre tank containing, as mentioned earlier, a calmed inlet pipe located at the bottom of the tank as well as a floating valve out-take pipe (suspended just below the water surface) that feeds water to tank 4 via a 50 mm diameter connecting pipe 100 mm from the base of both tanks.
- Tank 4: A 5,000 litre tank that is linked in series (as described above) to tank 3.
- Tank 5: A 5,000 litre tank that is linked to a first flush diverter (Marley NZ). The diverter is 300 mm diameter pipe 1.5 meters in length and has a flush volume capacity of 120 litres and contains a 1.25 mm diameter self-draining flow control valve.
- Tank 6: A 5,000 litre control tank.

The discharge overflows from all six tanks are through 80 mm diameter PVC pipes linked to 100 mm diameter storm water drainpipes.

***Recording of rainfall data:***
Rainfall data was recorded using a tipping bucket rain gauge and monitor. Rainfall (in millimetres) was recorded at the time of all sampling events, namely the amounts that had fallen in the previous 1 hour and 24 hours as well as the total rainfall over the entire sampling period.

***Water sample collection:***
Since 12/10/2005 a total of 1700 roof-collected rainwater samples have been collected for baseline microbiological analysis. 100 ml water samples were collected aseptically from all four taps of each tank in appropriately labelled sterile 120 ml plastic bottles. Water samples from the first flush diverter were collected from the control valve drainage water or from the residue in bottom of the diverter. All water samples were placed on ice packs in a chilli-bin and transported to the laboratory, usually within 30 minutes, and processed within 2 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 Colilert 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.

## RESULTS

There were 25 sampling events from 12/10/2005 to 20/07/2006. The rainfall intensities for the 24 hours prior to sampling ranged from 0.0 mm to 26.7 mm with an average of 8.94 mm. The total rainfall for the entire sampling period was 1262.7 mm. Tank 6 was completely full of water on 12/10/2005 and tanks 1 and 2 on 26/11/05 and 30/11/05 respectively. Tank 5 was completely full on 24/11/05 and tanks 3 and 4 on the 21/03/06. From this date onwards all the tanks remained full and given the amount of rainfall, discharged excess water at regular intervals. Table 1 shows only the rainfall results and corresponding *Total coliform* and *Escherichia coli* counts of the 14 sampling events from 21/03/2006 to 20/07/2006 when all six tanks were full.

***Tank 1:*** During sampling events 12 to 18 the *Total coliform* and *Escherichia coli* counts from all 4 tap samples were low to zero but increased markedly at sampling event 19 (e.g. tap 19A: 1299.7 per 100 ml). At sampling event 20 both *Total coliform* and *Escherichia coli* counts were still high (e.g. tap 20D: 224.7 and 135.4 per 100 ml respectively). The bacterial counts then declined steadily to zero levels from sampling events 21 to 25 (12/04/06 – 20/07/06).

***Tank 2:*** During sampling events 12 to 18 the *Total coliform* counts from all 4 taps fluctuated from very high levels (e.g. tap 12A: 2419.2 per 100 ml) to low levels (e.g. tap 18D: 201.4 per 100 ml). The *Escherichia coli* counts were much lower and decreased from 307.6 to 9.8 per 100 ml over the same sampling period. From sampling event 19 to 25 the counts for both *Total coliforms* and *Escherichia coli* declined steadily to low levels (e.g. tap 19A: 41.3 and 2.0 per 100 ml; e.g. tap 25D: 9.7 and 8.5 per 100 ml).

***Tank 3:*** During sampling events 12 to 21 the *Total coliform* counts from all 4 taps were greater than 2419.2 per 100 ml. From sampling event 22 to 25 the counts decreased from 1203.3 to 53.8 per 100 ml respectively. Except for one high count (tap 12D: >2419.2 per 100 ml) the *Escherichia coli* counts in comparison were consistently low to zero during sampling events 12 to 25.

***Tank 4:*** Similarly to the tank 3 results the *Total coliform* counts from all 4 taps were greater than 2419.2 per 100 ml on most occasions during sampling events 12 to 20. From sampling event 21 to 25 however, the *Total coliform* counts were much lower overall than those for the corresponding period for tank 3. During the entire sampling period the majority of the water samples from all four tank 4 taps yielded zero *Escherichia coli* counts.

***Tank 5:*** Except on two occasions (e.g. tap 12B: 517.2 and tap 15D: 117.8 *Total coliforms* per 100 ml) all samples yielded low to zero counts for both *Total coliforms* and *Escherichia coli* during the entire sampling period.

***Tank 6:*** Except for samples taken during sampling events 19 to 22, the majority of the samples yielded low to zero counts for both *Total coliforms* and *Escherichia coli*.

***First flush diverter:*** In the majority of the water samples taken from the first flush diverter high levels of *Total coliforms* were found (e.g. sample 15A: 1986.3 and sample 19A: >2419.2 per 100 ml). The *Escherichia coli* counts were overall not as high as the *Total coliform* counts but only one sample was negative for *Escherichia coli*.

**ROOFWATER RESEARCH CENTRE STAGE 1 TRIALS**

| No. | Date | Rainfall | | Tank 1 | | Tank 2 | | Tank 3 | | Tank 4 | | Tank 5 | | Tank 6 | | First Flush | | No. KEY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 24 hr | Total | Tot | EC | Tot | EC | Tot | EC | Tot | EC | Tot | EC | Tot | EC | Tot | EC | |
| 12A | 21-Mar-06 | 14.9 | 352.5 | 8.5 | 3.1 | 2419.2 | 307.6 | >2419.2 | 31.3 | 0.0 | 0.0 | 5.2 | 2.0 | 4.1 | 1.0 | 687.7 | 88.6 | A = top tap |
| 12B | | 14.9 | | 4.1 | 2.0 | 1553.1 | 89.1 | >2419.2 | 178.5 | 3.1 | 0.0 | 517.2 | 0.0 | 8.4 | 3.0 | | | B = 2nd tap down |
| 12C | | 14.9 | | 45.0 | 2.0 | 35.4 | 9.7 | >2419.2 | 185.0 | >2419.2 | 0.0 | 2.0 | 0.0 | 5.2 | 4.1 | | | C = 3rd tap down |
| 12D | | 14.9 | | 31.8 | 2.0 | 344.8 | 18.1 | >2419.2 | >2419.2 | >2419.2 | 0.0 | 4.1 | 2.0 | 488.4 | 0.0 | | | D = bottom tap |
| 13A | 22-Mar-06 | 24.4 | 367.7 | 8.6 | 1.0 | 1732.9 | 248.9 | >2419.2 | 16.6 | >2419.2 | 0.0 | 0.0 | 0.0 | 5.2 | 0.0 | 1119.9 | 77.1 | |
| 13B | | 24.4 | | 8.6 | 4.1 | 1732.9 | 131.3 | >2419.2 | 69.5 | >2419.2 | 7.2 | 0.0 | 0.0 | 7.4 | 3.1 | | | |
| 13C | | 24.4 | | 8.6 | 5.2 | 1203.3 | 131.3 | >2419.2 | 70.0 | >2419.2 | 7.3 | 1.0 | 0.0 | 10.9 | 0.0 | | | |
| 13D | | 24.4 | | 20.1 | 4.1 | 1203.3 | 135.4 | >2419.2 | 38.6 | >2419.2 | 19.3 | 2.0 | 1.0 | 10.7 | 2.0 | | | |
| 14A | 23-Mar-06 | 8.2 | 427.2 | 10.9 | 3.1 | 1986.3 | 107.1 | >2419.2 | 40.5 | >2419.2 | 9.8 | 0.0 | 0.0 | 3.1 | 1.0 | 249.5 | 121.0 | |
| 14B | | 8.2 | | 4.1 | 3.0 | 1203.3 | 98.5 | >2419.2 | 43.7 | >2419.2 | 9.7 | 0.0 | 0.0 | 10.9 | 1.0 | | | |
| 14C | | 8.2 | | 6.3 | 1.0 | 1553.1 | 88.9 | >2419.2 | 21.3 | >2419.2 | 7.4 | 3.1 | 0.0 | 5.2 | 2.0 | | | |
| 14D | | 8.2 | | 9.6 | 7.4 | 1203.3 | 80.3 | >2419.2 | 21.1 | >2419.2 | 60.1 | 1.0 | 0.0 | 5.2 | 2.0 | | | |
| 15A | 24-Mar-06 | 12.2 | 439.9 | 0.0 | 0.0 | 1553.1 | 63.1 | >2419.2 | 41.1 | >2419.2 | 10.9 | 0.0 | 0.0 | 1.0 | 0.0 | 1986.3 | 13.5 | |
| 15B | | 12.2 | | 1.0 | 1.0 | 648.8 | 72.2 | >2419.2 | 32.0 | >2419.2 | 9.6 | 2.0 | 0.0 | 1.0 | 0.0 | | | |
| 15C | | 12.2 | | 1.0 | 0.0 | 1119.9 | 90.6 | >2419.2 | 30.7 | >2419.2 | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 15D | | 12.2 | | 1.0 | 1.0 | 1046.2 | 91.1 | >2419.2 | 25.9 | >2419.2 | 9.8 | 117.8 | 0.0 | 7.4 | 0.0 | | | |
| 16A | 26-Mar-06 | 1.0 | 443.2 | 2.0 | 1.0 | 235.9 | 64.5 | >2419.2 | 8.6 | >2419.2 | 4.1 | 1.0 | 0.0 | 1.0 | 0.0 | 129.1 | 3.1 | |
| 16B | | 1.0 | | 1.0 | 1.0 | 365.4 | 36.9 | >2419.2 | 12.2 | >2419.2 | 2.0 | 0.0 | 0.0 | 1.0 | 0.0 | | | |
| 16C | | 1.0 | | 1.0 | 0.0 | 325.5 | 65.0 | >2419.2 | 16.1 | >2419.2 | 3.1 | 1.0 | 0.0 | 1.0 | 0.0 | | | |
| 16D | | 1.0 | | 0.0 | 0.0 | 488.4 | 42.6 | >2419.2 | 5.1 | >2419.2 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 17A | 27-Mar-06 | 3.2 | 510.2 | 3.1 | 0.0 | 2419.2 | 38.4 | >2419.2 | 3.1 | >2419.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 547.5 | 19.8 | |
| 17B | | 3.2 | | 1.0 | 0.0 | 461.1 | 27.5 | >2419.2 | 6.3 | >2419.2 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 17C | | 3.2 | | 1.0 | 0.0 | 696.7 | 20.1 | >2419.2 | 3.1 | >2419.2 | 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 17D | | 3.2 | | 2.0 | 0.0 | 410.6 | 25.6 | >2419.2 | 5.1 | >2419.2 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 18A | 30-Mar-06 | 0.0 | 518.4 | 0.0 | 0.0 | 248.1 | 14.3 | >2419.2 | 3.1 | 2419.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15 | 0.0 | |
| 18B | | 0.0 | | 0.0 | 0.0 | 156.5 | 12.1 | >2419.2 | 1.0 | 1986.3 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 18C | | 0.0 | | 0.0 | 0.0 | 275.5 | 9.8 | >2419.2 | 1.0 | 2419.2 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 18D | | 0.0 | | 0.0 | 0.0 | 201.4 | 9.8 | >2419.2 | 0.0 | >2419.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 19A | 7-Apr-06 | 6.4 | 547.6 | 1299.7 | 1299.7 | 41.3 | 2.0 | >2419.2 | 2.0 | >2419.2 | 0.0 | 4.1 | 3.1 | 816.4 | 816.4 | >2419.2 | >2419.2 | |
| 19B | | 6.4 | | 980.4 | 980.4 | 13.4 | 2.0 | >2419.2 | 0.0 | 67.0 | 0.0 | 0.0 | 0.0 | 816.4 | 816.4 | | | |
| 19C | | 6.4 | | 9.8 | 9.8 | 88.2 | 4.1 | >2419.2 | 0.0 | 307.6 | 0.0 | 0.0 | 0.0 | 579.4 | 547.5 | | | |
| 19D | | 6.4 | | 13.2 | 13.2 | 14.5 | 7.4 | >2419.2 | 2.0 | >2419.2 | 0.0 | 3.1 | 2.0 | 235.9 | 224.7 | | | |
| 20A | 9-Apr-06 | 11.7 | 559.8 | 178.2 | 157.6 | 3.0 | 2.0 | >2419.2 | 1.0 | 866.4 | 0.0 | 0.0 | 0.0 | 172.5 | 101.2 | 35.4 | 7.2 | |
| 20B | | 11.7 | | 365.4 | 190.4 | 3.0 | 1.0 | >2419.2 | 0.0 | 1203.1 | 0.0 | 0.0 | 0.0 | 166.4 | 93.3 | | | |
| 20C | | 11.7 | | 214.3 | 160.7 | 3.0 | 2.0 | >2419.2 | 0.0 | 727.0 | 0.0 | 0.0 | 0.0 | 148.3 | 98.5 | | | |
| 20D | | 11.7 | | 224.7 | 135.4 | 5.1 | 1.0 | >2419.2 | 0.0 | 2419.2 | 0.0 | 1.0 | 0.0 | 131.3 | 93.3 | | | |
| 21A | 12-Apr-06 | 1.3 | 565.7 | 34.5 | 29.2 | 1.0 | 0.0 | >2419.2 | 0.0 | 5.2 | 0.0 | 0.0 | 0.0 | 39.1 | 33.2 | 47.2 | 9.2 | |
| 21B | | 1.3 | | 29.9 | 21.8 | 2.0 | 0.0 | >2419.2 | 0.0 | 5.3 | 0.0 | 0.0 | 0.0 | 53.7 | 36.4 | | | |
| 21C | | 1.3 | | 28.8 | 22.6 | 2.0 | 1.0 | >2419.2 | 0.0 | 17.1 | 0.0 | 0.0 | 0.0 | 36.8 | 27.2 | | | |
| 21D | | 1.3 | | 19.9 | 14.5 | 4.0 | 0.0 | >2419.2 | 0.0 | 24.3 | 0.0 | 0.0 | 0.0 | 24.9 | 20.3 | | | |
| 22A | 26-Apr-06 | 21.8 | 600.7 | 75.9 | 62.7 | 18.7 | 4.1 | 1203.3 | 0.0 | 0.0 | 0.0 | 25.9 | 22.3 | 79.4 | 48.8 | 1553.1 | 1299.7 | |
| 22B | | 21.8 | | 70.8 | 57.1 | 8.6 | 4.1 | 1553.3 | 0.0 | 0.0 | 0.0 | 23.8 | 23.8 | 74.3 | 59.8 | | | |
| 22C | | 21.8 | | 7.4 | 6.3 | 4.1 | 2.0 | 1732.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 48.1 | 45.0 | | | |
| 22D | | 21.8 | | 57.6 | 43.9 | 3.1 | 2.0 | 727.0 | 0.0 | 0.0 | 0.0 | 11.0 | 9.8 | 101.4 | 86.0 | | | |
| 23A | 12-May-06 | 10.4 | 646.3 | 4.1 | 2.0 | 9.7 | 1.0 | 387.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.1 | 3.1 | 1119.9 | 42.8 | |
| 23B | | 10.4 | | 3.1 | 2.0 | 8.6 | 1.0 | 224.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 1.0 | | | |
| 23C | | 10.4 | | 1.0 | 1.0 | 12.2 | 0.0 | 307.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.1 | 5.0 | | | |
| 23D | | 10.4 | | 4.1 | 1.0 | 13.4 | 1.0 | 261.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 1.0 | | | |
| 24A | 14-Jul-06 | 0.0 | 1155.7 | 0.0 | 0.0 | 17.3 | 7.4 | 224.7 | 65.7 | 29.2 | 18.5 | 0.0 | 0.0 | 4.0 | 3.0 | >2419.2 | 920.8 | |
| 24B | | 0.0 | | 0.0 | 0.0 | 13.2 | 4.1 | 112.4 | 52.8 | 30.5 | 18.5 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 24C | | 0.0 | | 0.0 | 0.0 | 26.5 | 18.9 | 154.1 | 80.5 | 35.8 | 13.1 | 0.0 | 0.0 | 2.0 | 1.0 | | | |
| 24D | | 0.0 | | 0.0 | 0.0 | 17.5 | 11.0 | 75.9 | 31.4 | 12.0 | 6.3 | 0.0 | 0.0 | 2.0 | 1.0 | | | |
| 25A | 20-Jul-06 | 0.2 | 1262.7 | 0.0 | 0.0 | 5.2 | 3.1 | 18.7 | 10.9 | 8.6 | 5.2 | 0.0 | 0.0 | 3.0 | 0.0 | 866.4 | 173.0 | |
| 25B | | 0.2 | | 0.0 | 0.0 | 8.4 | 6.2 | 28.8 | 6.3 | 20.3 | 8.6 | 0.0 | 0.0 | 2.0 | 0.0 | | | |
| 25C | | 0.2 | | 0.0 | 0.0 | 5.2 | 3.0 | 31.3 | 9.7 | 14.8 | 9.8 | 0.0 | 0.0 | 1.0 | 0.0 | | | |
| 25D | | 0.2 | | 0.0 | 0.0 | 9.7 | 8.5 | 53.8 | 9.8 | 6.2 | 4.1 | 0.0 | 0.0 | 3.1 | 0.0 | | | |

Table 1: Rainfall, *Total coliform* and *Escherichia coli* results from 21/03/2006 to 20/07/2006.

## DISCUSSION

Total coliforms, which include both faecal and environmental coliform bacteria, are sometimes used to monitor drinking water quality and indicate the probable contamination of the water supply by organic material (e.g. soil, roots of plants, vegetation, grain). While total coliforms can also be found in the intestinal tract of humans and other animals, they are inherently environmental organisms and are regarded as non-faecal coliforms which, if detected in a water sample, indicate that the possibility of faecal contamination needs to be checked. *Escherichia coli* (*E.coli*), a thermotolerant faecal coliform organism, is a normal inhabitant of the intestinal tract of humans and other warm-blooded animals and is increasingly being used as an alterative to total coliforms as indicators of faecal pollution (APHA 1998).

In this study we have found that levels of *Total coliform* and *Escherichia coli* were overall much higher in the tanks situated at the northern end of the site (Tanks 2, 3 and 4) than the bacterial levels in Tanks 1 and 6, situated at the southern end. Furthermore, the pattern of *Total coliform* and *Escherichia coli* levels in tanks 1 and 6 were remarkably similar. The reason for this could be explained by the results of a recent study involving the analysis of direct roof run-off at an urban housing development in Newcastle, Australia, which indicated that airborne microorganisms represented a significant contribution to the bacterial load of

roof water (Evans *et al.* 2006). These authors showed that wind velocities had a strong influence on the bacterial load and that the composition of the load varied with wind direction. In other words while rainfall events clearly influenced the bacterial levels that we found in this study, the direction of the rainfall (whether southerly or northerly) could also have impacted on the levels of indicator organisms.

Under normal circumstances bacteria would be expected to die off naturally in rainwater storage tanks. 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 (Lye 1992). In this study we found that the overall sedimentation of *Total coliforms* and *Escherichia coli* from the top of the tank to the bottom of the tank was slow and variable in Tanks 1,2,3, 4 and 6. We would have expected to find markedly higher bacterial counts in the bottom tap (C and D) water samples from the tanks. A reason for the slow sedimentation could have been due to the fact that there were only overflow water discharges from the tanks as opposed to periodically drawing off various volumes of water through actual usage.

An Australian study showed that while roof water and *in situ* tank water exceeded the *Australian Drinking Water Guidelines* for *Total* and *Faecal coliforms* by a considerable margin (average tank counts of 830 and 120 per 100 ml respectively), the highest counts occurred immediately after major rainfall events which washed organic material from the roof gutters into the tanks. Nevertheless, the authors demonstrated a marked reduction in the bacterial counts over time suggesting that the rainwater tanks have a self-disinfection action. (Coombes *et al.* 2000). While we did find a steady decline in the *Total coliform* and *Escherichia coli* counts over time in Tank 1 it is not clear whether the decline was due to self-disinfection or if the decline was due to the gravitational and/or siphonic action of the vacuum system in the tank. Similarly in Tank 2 the marked reduction in the *Total coliform* and *Escherichia coli* counts from sampling event 19 to 25 may have been due to a combination of natural bacterial die-off and the siphonic action of the this vacuum system.

An unexpected finding in this study was the high *Total coliform* counts that we found in Tanks 3 and 4 (the tanks linked in series). Since the majority of the corresponding *Escherichia coli* counts in these two tanks were low to zero, the high *Total coliform* counts could have been due to slow sedimentation of environmental organisms or other sources of contamination present in these tanks. First order kinetics indicate that there should be a considerable reduction in pathogen counts if two or more tanks are used in series for water storage rather than one single tank. For example it has been postulated that a faecal contamination of 5,000 *E.coli* per 100ml is reduced to some 90 *E.coli* per 100ml after 100 days storage in a 60 cubic metre tank. When two 30 cubic metre tanks operate in series, the result is 6 *E.coli* per 100ml in the second tank (Ashworth 2004). Preliminary studies to investigate this hypothesis have been carried out at Loughborough University in the UK and have found that two tanks are indeed more effective in removing thermotolerant coliforms than a single tank (Ensslin, 2005).

As shown in the results section the water samples from Tank 5 (linked to the first flush diverter) consistently yielded low to zero *Total coliforms* and *Escherichia coli* throughout the study. Conversely, the majority of the water samples taken from the first flush diverter yielded high levels of *Total coliforms* and only one sample was negative for *Escherichia coli*. While exposure to direct sunlight and desiccation on the roof can destroy many bacteria over time it has been 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 (Yaziz *et al.* 1989). 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 also 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 first foul flush volume so that the water may be collected and stored after a shorter "cleansing period". Although 20 to 25 litres has been suggested as being as a suitable first foul flush volume (WHO 2004) there is no universal agreement on just how much roof run-off should be diverted and whether the diversion should be based on volume or rainfall depth, duration, or intensity. A popular rule of thumb is that the amount to be diverted should be the equivalent of 2 mm of rain over the area of roof.

## CONCLUSIONS

Important conclusions that may be drawn from this preliminary study on measures for improving the quality of roof-collected rainwater are:

- The overall sedimentation of *Total coliforms* and *Escherichia coli* from the top of the tank to the bottom of the tank was slow and variable in Tanks 1,2,3, 4 and 6.
- While we did find a steady decline in the *Total coliform* and *Escherichia coli* counts over time in Tanks 1 and 2, it is not clear whether the decline was due to self-disinfection or if the decline was due to the gravitational and/or siphonic action of the vacuum systems in the tank.
- Wind direction and rainfall intensity significantly influence the quality of roof-collected rainwater.
- The quality of the water improves dramatically with the use of first flush diverters.

A more robust assessment of the effectiveness of products and systems will be carried out in stage two of this study. In order to investigate the full diversity of microbial contamination and tank water ecology, seeded water samples of known quantities of *Escherichia coli, Giardia* and *Cryptosporidium* will be used to accurately determine the sedimentation rates and retention times of these organisms. Further research will also be carried out to quantify the minimum first flush volumes of roof-collected rainwater that would be sufficient to significantly reduce the pollutants in a storage tank. This should provide a more definitive understanding of the rules-of-thumb pollution factor calculations that have been proposed for first flush diversion volumes. These rules-of-thumb have a large number of built in assumptions that need to be substantiated.

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***References:***

Abbott, S.E., Caughley, B.P. and S.J. Bell (2004). Microbiological health risks of roof-collected rainwater – A Review**.** *In Proceedings: National Environmental Health Conference War Memorial Centre, Napier* – NZ Institute of Environmental Health.

Abbott, S.E., Douwes, J. and B.P Caughley (2006). A survey of the microbiological quality of roof-collected rainwater of private dwellings in New Zealand *In Proceedings: Water 2006 International Conference Hyatt Regency Hotel Auckland.*

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*

APHA. (1998). Standard methods for the examination of water and wastewater. 20th ed. *American Public Health Association. Washington. D.C.*

Ashworth, J. (2004). Simple measures to improve tank water quality. *Water & Wastes in New Zealand*. ***120****; September pp. 30-31.*

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.*

Ensslin, C.H. (2005). Rainwater tanks in series. *Master of Science Thesis. Loughborough University, England.*

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.*

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

Lye, D.J. (1992). Microbiology of rainwater cistern systems. *Journal of Environmental Science and Health. **A2**; 2123-216.*

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., Hope, V., Lewis, G., Whitmore, J. and W. Gao. (2001). Contamination of potable roof-collected rainwater in Auckland, New Zealand. *Water Research. **35**;1518-1524.*

WHO. (2004). Guidelines for drinking water quality. 3rd Edition Volume 1 (Recommendations). *World Health Organization. Geneva*.

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