Water Quality and Health Risks from Urban Rainwater Tanks

Heather Chapman[1], Tony Cartwright[1, 2], Rob Huston[1, 3]
Joanne O'Toole[1, 4]

[1] CRC for Water Quality and Treatment

[2] Sydney Water Corporation

[3] Griffith University

[4] Monash University

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Cooperative Research Centre for Water Quality and Treatment
Private Mail Bag 3
Salisbury SA 5108
AUSTRALIA

Telephone: +61 8 8259 0351
Fax: +61 8 8259 0228
E-mail: crc@sawater.com.au
Web site: www.waterquality.crc.org.au

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Foreword

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Research Officers: [1]Heather Chapman, [1, 2]Tony Cartwright, [1, 3]Rob Huston, [1, 4]Joanne O'Toole

Project Leader: Tony Cartwright

Research Nodes: [1] CRC for Water Quality and Treatment

[2] Sydney Water Corporation

[3] Griffith University

[4] Monash University

CRC for Water Quality and Treatment project No 2.0.2.6.0.4 'Assessment of Water Quality and Health Risk Analysis of Water from Urban Rainwater Tanks'.

This report is one output of the project. The other is 'Research Report 39: Guidance Manual for the Design and Installation of Urban Roofwater Harvesting Systems in Australia (Edition 1) (Chapman *et al.* 2008).'

Executive Summary

A literature review of public health aspects of rain water tanks was published as Occasional Paper 10 by the CRC Water Quality and Treatment in 2005 (Sinclair et al. 2005).

This report documents the findings of the CRC for Water Quality and Treatment research project 'Water Quality and Health Risks from Urban Rainwater Tanks'. This survey involved field sampling and laboratory analysis of water quality in several locations around Australia that took place from August 2004 – April 2005. In addition, this report presents and discusses data recently gathered from other water quality surveys by CRC project partners. Together these studies contribute to an understanding of the health risk associated with urban rainwater usage. This report discusses rainwater quality (chemical and microbiological) for various end uses in urban areas where a potable supply exists and discusses further research.

Results of the following rainwater tank water quality surveys are included in this report:

- CRC for Water Quality and Treatment, National survey (August 2004 – April 2005)
- Yarra Valley Water and Centre for Education and Research in Environmental Strategies (YVW/CERES) Survey (December 2003 – September 2004)
- Brisbane City Council Survey (July 2003 – March 2005)
- Mutitjulu Survey (May 2004-August 2005)
- Data from Department of Natural Resources and Mines, Qld.

Chemical Water Quality

Overall the chemical water quality analysis shows that rainwater in Australia is soft water with low total dissolved solids or salts, which is in agreement with studies in other countries (Hontoria *et al.* 2003). Water from tanks in urban Australia is generally slightly acidic but cannot be regarded as acid rain with the exception of one sample from Adelaide with a pH of 3. Acid rain is defined as having a pH lower than that of pure water in equilibrium with CO_2 in the atmosphere, which is a pH of 5.6 (Avila and Alarcon, 1999; Hu *et al.* 2003). The lack of acid tank water is an indication that industrial and motor vehicle emissions are not significant inputs to rainwater in Australia. However, storage in tanks may neutralise some acidity through reaction with dust and organic matter also collected in the tank. Study of 29 tanks in Brisbane shows that variability of tank water pH is much greater than the municipal supply. This high variation in water quality between tanks and over time makes it more difficult for assessment of the risk with different end uses of tank water. The soft and sometimes acidic nature of the rainwater is likely to cause corrosion of pipes and this is suggested from the results of the Brisbane and Melbourne data, where tank water passing through the hot water system had higher levels of copper and greater incidence of detection for lead and nickel. The generally soft water may also be a risk for electrical hot water systems that have a sacrificial anode designed for hard water such as in Brisbane municipal supply. This could lead to an overactive anode and production of explosive hydrogen gas.

The addition of limestone ($CaCO_3$) chips or powder to tanks has been proposed by Conlan and Longhurst (1993) to neutralise acidity and increase the calcium content and hardness of tank water as calcium compounds are known to be a major buffering compound in rainwater. It is recommended that the effectiveness of this measure in decreasing the corrosiveness and softness of tank water is validated in real tanks before it is recommended in practice.

Lead was found to be above the 2004 Australian Drinking Water Guidelines (ADWG 2004) in 5-10% of urban tanks. Elevated concentrations of copper, nickel and other metals were also detected in rainwater that has passed through a hot-water system.

When examining other chemical contaminants on an individual basis, in the majority of situations the chemical water quality from rainwater tanks is unlikely to cause any chemical-related health problems

if drunk. However, this is not so in all tanks or at all times. Some hydrocarbons, phthalates and herbicides have been detected in some samples indicating that they are present on occasions. For the Polycyclic Aromatic Hydrocarbons (PAHs), excluding a couple of samples in Melbourne, they were not measured with significant sensitivity to comment on their presence affecting health.

Microbiological Water Quality

Results obtained from rainwater tank studies described in this report showed that tank water is of relatively poor microbiological quality compared with conventional Australian urban water supplies. Furthermore, the detection of enteric bacterial pathogens, *Campylobacter* spp and *Salmonella* spp bacteria in some tank waters confirmed the plausibility of gastrointestinal infection arising from these bacterial enteric pathogens when tank water is consumed as drinking water or incidentally from domestic hot water use in instances where water is not heated sufficiently to achieve enteric pathogen inactivation.

These findings highlight that research data is required to verify that the range of domestic water heating system regimes, including instantaneous and solar systems, operated according to current domestic hot water storage regulations, result in enteric pathogen inactivation. Critical control points can include hot water systems as a means of disinfection (O'Toole et al. 2004; Jayaratne et al. 2006; Spinks, 2003). The thermal inactivation of water-borne pathogenic and indicator organisms at sub-boiling temperatures has been recently reported (Spinks et al. 2006).

Results from the described studies supplement existing data about the prevalence of bacterial enteric pathogens in Australian roof collected rainwater tanks but further research is required. Monitoring of rainwater tanks for enteric pathogens as part of the NHMRC funded randomised, double-blinded intervention study being conducted in 2007/2008 in Adelaide provides an opportunity for supplementation of existing datasets in parallel with the monitoring of the health status of householders using rainwater for drinking purposes.

The relatively small number of rainwater tanks surveyed, and the variability of the tanks with respect to materials, roof catchment characteristics and cleaning regimes in the background descriptive study, hindered the detection of relationships between rainwater tank characteristics and operating protocols and microbial water quality. Similarly, the Brisbane City Council study results did not allow the elucidation of the relationship between materials and roof catchment characteristics with the microbiological water quality of input water due to the confounding effect of disinfected reticulated water used to top-up rainwater tanks.

Possible ways in which this information might be obtained economically include appending rainwater tank water quality surveys to health studies where large enough numbers of rainwater tanks are available to be surveyed on multiple occasions. The NHMRC-funded randomised, double-blinded intervention study being conducted in 2007/2008 provides such an opportunity as relatively high numbers of tanks (300) will be fully described in terms of physical characteristics.

In the absence of opportunities to conduct water quality monitoring as part of other studies, experiments using indicator micro organisms fit for purpose potentially provide the best and most economical means to investigate strategies that minimise microbial contamination of roof-collected rainwater. This is because such studies allow levels of contamination and rainfall to be manipulated to reflect worst-case scenarios and rainwater tank variables can be controlled.

Monitoring for *Legionella* was performed in the National survey and in the YVW/CERES study. *Legionella* species were detected in eight out of thirty five (23%) rainwater tanks and 10 out of 67 (15%) samples in the National survey. No *Legionella* were detected in YVW/CERES samples. *Legionella pneumophilia* (sero-group 1 and 2-14) bacteria were not detected in any rainwater tank samples.

A potential increase in the risk of legionellosis associated with rainwater tank supplies over conventional drinking water supplies cannot be assumed based on these results for a number of reasons. Firstly, the prevalence of *Legionella* species in Australian conventional drinking water supplies using a similar detection methodology as in this study is largely unknown. Secondly, detected

Legionella bacteria were not speciated as part of this study and *Legionella* prevalence data for rainwater tank supplies is scant.

Current Australian regulations relating to hot water storage temperature (provided that they are followed) are an effective intervention measure for the control of *Legionella* bacteria irrespective of the source of water for domestic use. Hence, an increased prevalence of *Legionella* bacteria in rainwater tank supplies, as compared with conventional drinking water supplies, only gains relevance where changes are contemplated to regulations pertaining to domestic hot water system operation. Further research to ascertain the prevalence of *Legionella* in domestic rainwater tanks is therefore not recommended at this stage and would only be required to quantify the risk of legionellosis in situations of non-compliance with current regulations or where changes to hot water storage temperature regulations, such as those motivated by energy saving initiatives, are contemplated.

Research into the prevalence of *Mycobacterium* species in rainwater tank water is likewise not recommended at this stage premised on the maintenance of current hot water storage regulations and associated with the relative cost and availability of analytical tests for *Mycobacteria* species of interest that might be present in rainwater.

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Abbreviations

ACTEW	Australian Capital Territory Energy and Water
ATSIC	Australian and Torres Strait Islander Commission
ADWG	Australian Drinking Water Guidelines
AWQC	Australian Water Quality Centre
BCC	Brisbane City Council
BTX	Benzene, Toluene, Xylene
CAT	Centre for Appropriate Technology
CERES	Centre for Education and Research in Environmental Strategies
CPA	4-chlorophenoxy acetic acid
CRC	Cooperative Research Centre
DBP	Disinfection By-products
DOC	Dissolved Organic Carbon
HPC	Heterotrophic Plate Count
HWS	Hot Water System
NH&MRC	National Health and Medical Research Council
PAH	Polycyclic Aromatic Hydrocarbons
POU	Point of Use
RWT	Rain Water Tank
TDS	Total Dissolved Solids
UV	Ultra Violet
WHO	World Health Organisation
YVW	Yarra Valley Water

1 Introduction

This report documents the findings of the CRC for Water Quality and Treatment National survey from the Project #2.0.2.6.0.4 entitled 'Water Quality and Health Risks from Urban Rainwater Tanks'. In addition, it presents and discusses data, recently gathered from other work conducted by project participants, which contributes to our understanding of the health risks associated with urban rainwater usage.

1.1 Report Structure

This report is divided into 8 sections.

Section 1 Introduction provides the context for the CRC for Water Quality and Treatment research project 'Water Quality and Health Risks from Urban Rainwater Tanks'. It summarises the literature review conducted in Stage 1 of the project and refers to other relevant documentation associated with this study.

Section 2 describes and presents data from the rainwater tank National survey which is the primary component of Stage 2 of the CRC project.

Section 3 describes and presents relevant water quality data from ancillary rainwater tank studies (CRC and non CRC studies), including a discussion of results.

Section 4 discusses and presents overall conclusions and recommendations arising from all described studies.

Sections 5, 6 and 7 of the report contain the references, acknowledgements and appendices respectively.

1.2 Background

1.2.1 Literature reviews and workshops

The Stage 1 Literature Review was undertaken in 2003 and the relevant information from that review is summarised in this document or reported in Sinclair et al. 2005). The review comprised the collection and assessment of existing information on quality of the water from rainwater tanks installed in urban and regional areas in Australia and other locations. In addition to an examination of the statistical aspects of available data with consideration of the variability of water quality parameters, those contaminants considered to be the most significant in terms of public health risks for rainwater tanks in urban areas of Australia were identified. The literature survey found little data on health risks from studies conducted in Australia and a large gap in understanding of water quality characteristics in rainwater tanks located in urban and industrial areas, particularly from physico-chemical and human health perspectives. There have been studies that examine the hydrological, design and economic aspects of using rainwater tanks for outdoor uses and toilet flushing (Coombes et al.1999; 2000).

It was not possible to extrapolate from the overseas literature the expected tank water quality for the Australian situation because each study was significantly influenced by local conditions and the constraints of the specific study methodology. The review of available information found there to be very few intensive reports reviewing the quality of rainwater verses the allowable end uses for rainwater. Also, the impacts on water quality from industrial pollution, traffic, roof and tank materials were found to have not been studied in any detail.

The literature review, which was completed in October 2003, included summaries of relevant papers and reports evaluated with respect to parameters examined, methodology (sampling regime and statistical analysis) and the relevance of the study setting to the urban Australian situation. The general finding of Stage I was that the available data were limited both in quantity and quality, and in relevance. With the exception of the studies carried out by NSW Health, most were found to be based on small numbers of rainwater systems and/or small numbers of samples from each tank, and the data were not statistically robust. Information on the variability of water quality over time was limited, and conclusions on the effects of roof or tank materials or design may not have been reliable.

From the Stage 1 assessment and current knowledge about potential contaminants in urban areas, the following general recommendations were made regarding water quality monitoring for the Stage 2 study:

- Microbiological quality - monitoring for indicator organisms be given the highest priority (*E. coli*, heterotrophic plate count bacteria and total coliforms), followed by testing for specific bacterial enteric pathogens that have been detected in rainwater tanks and have been associated with disease outbreaks (*Salmonella*, *Campylobacter*). Monitoring for the protozoal pathogens *Giardia* and *Cryptosporidium* was considered a third priority.
- Aesthetic and physicochemical quality – monitoring for health related parameters including lead, copper and benzo-(α)-pyrene. It was considered that tests for lead and copper (depending on the analysis method) may also have yielded information on other metals although these were unlikely to be present at problematic levels. Non-health related parameters monitored include pH, turbidity and zinc.
- Other factors – to compare the effect of a number of factors such as the presence or absence of first flush devices, different roof materials, different tank materials and different point of use devices.

Recommendations derived from Stage 1 of the study provided the basis for the design of Stage 2. However, iterations in the Stage 2 project development process gave rise to the changes to the planned monitoring program. This occurred as a consequence of discussion with project partners and discrepancies between the planned National survey monitoring schedule and the schedules for other related rainwater tank studies. In addition, as the monitoring program was subject to cost constraints and logistical restrictions (e.g. laboratory capabilities etc.), monitoring for some parameters was not undertaken (e.g. *Giardia*, *Cryptosporidium*) even though it had been recommended. Furthermore, laboratories did not monitor tank waters for the same suite of chemicals, particularly pesticides. Hence there is only partial consistency in the suite of chemicals monitored between areas. Consequently these constraints did not allow statically robust data to be obtained with the National survey - at best enabling only ‘descriptive’ summary data to be collected.

A workshop held on the 24th of June 2003 identified the following key issues to address the shortfall of available information relevant to Australian conditions and the content of Stage 2 of the project:

- The study is to concentrate on urban rainwater tanks where a potable supply exists.
- There is a large gap in understanding of water quality characteristics in rainwater tanks from a physico-chemical perspective, particularly in highly urbanised areas. Analysis of heavy metals, PAHs and benzene-toluene-xylene (BTX) (emissions from vehicles) were to be included in the study.
- From a microbiological viewpoint, the literature reviews showed that potentially pathogenic organisms frequently occur in rainwater tanks. Thus an extensive program to monitor pathogenic organisms was deemed not to be necessary.
- There is a lack of longitudinal data for variations in water quality and the study sought to fill this knowledge gap and investigate the importance of climate variation to water quality.
- The outcomes of the study will contribute to a document that underpins the installation, operation and management of rainwater tanks in the urban context.

Stage 2 of the CRC for Water Quality and Treatment’s project ‘Assessment of Water Quality and Health Risk Analysis of Water from Rainwater Tanks (Project 2.6.0.4)’ was approved by the CRC for Water Quality and Treatment’s Board on 9 December 2003.

Discussions with various CRC parties over the months after the workshop highlighted that there were several projects involving urban rainwater tanks either recently completed, underway or about to start, and these are listed below:

(i) Water quality study on two facilities containing rainwater tanks in Centre for Education and Research in Environmental Strategies (CERES) in Melbourne. Installation completed in November 2003. Yarra Valley Water (YVW) commenced the 12 month trial monitoring program in December 2003.

(ii) Water quality study on 29 rainwater tanks in Brisbane by Brisbane City Council (BCC).

(iii) Mutitjulu (Northern Territory) study on pathogens and temperature profiling of the tanks.

(iv) Studies carried out in Queensland by the Department of Natural Resources, Mines and Water.

It was therefore decided that the rainwater tank project would incorporate these existing activities and endeavour to add value by supplementing the planned monitoring programs where appropriate and feasible. Details and the findings of the YVW /CERES and BCC studies are included in this report as a consequence of this decision.

The decision to focus on the verification of critical control points in removing organisms including hot water systems gave rise to the commissioning of an internal CRC for Water Quality and Treatment issues paper regarding the assessment of potential health risks and effectiveness of control measures for *Legionella* bacteria. This paper was posted on the CRC for Water Quality and Treatment participant website in August 2004 (O'Toole et al. 2004).

The objectives of the Issues paper were:

- To determine if a rainwater supply poses an increased risk of amplification of *Legionella* in hot water systems compared with a conventional potable water supply
- To determine if certain types of hot water units pose an increased risk of amplification of *Legionella* compared with other types of hot water units
- To recommend any additional testing or monitoring requirements in existing projects involving urban rainwater tanks in Brisbane (BCC rainwater tank monitoring project) or Melbourne (YVW / CERES rainwater project).

Recommendations arising out of the hot water issues paper were that in order to achieve the stated objectives, additional testing or monitoring in existing Brisbane and Melbourne projects was required. Of particular importance was generating data to enable a comparison of the prevalence of *Legionella* in rainwater and conventional tap water. Collection of temperature profile data for solar (and other) hot water systems in a variety of localities to inform health risk assessment and management associated with hot water units was also recommended. It was also recommended that the operational practices of householders be surveyed to ascertain the extent to which hot water system temperatures are 'manipulated' at the household level.

One outcome arising from the hot water issues paper recommendations was that a monthly monitoring of both rainwater tanks at the Melbourne CERES site for *Legionella* bacteria was appended to the existing microbiological monitoring program. In addition, monitoring of the solar pre-heater water temperature at the CERES café hot water storage was initiated to gain information regarding the temperature range of solar heated stored water in the Melbourne locality. A decision was also made to collect relevant hot water temperature data where available.

Further to this, the hot water issues paper focused attention on stored solar heated hot water temperatures and the implications of operation of solar hot water systems without a temperature booster. This resulted in the seeking out of temperature information for solar hot water systems that may have been collected in various Australian localities as part of other studies. Relevant temperature monitoring and other data has been collected by the Department of Natural Resources Queensland as part of their Brisbane Healthy Home project (Gardner and Miller, pers. comm.).

In addition to the draft CRC Stage 1 research report, a CRC for Water Quality and Treatment Occasional paper (Number 10) entitled Public Health Aspects of Rainwater Tanks in Urban Australia was published (Sinclair et al., 2005). This report was commissioned by the Department of Human Services Victoria from the CRC for Water Quality and Treatment and the Australian Centre for Human Health Risk Assessment. Commissioning of the report arose from concern among health authorities that the potential health risks from consumption of rainwater and other household uses should be better documented and understood, particularly with regard to the urban Australian setting. This level of concern was based upon the likely greater variability in tank water as compared with a reticulated water supply, attributed in part to the transferral of responsibility for operation and maintenance to the individual householder, as compared with a regulated and centrally operated conventional tap water supply.

The Occasional paper reviews available literature on rainwater tanks and summarises the evidence related to health risks associated with the consumption of water from rainwater tanks. The assessment of evidence focuses on the urban Australian setting, and also considers risks relating to the direct connection of such supplies to the reticulated water system. The quality and scope of the evidence are also assessed and gaps in the literature are identified. The report also includes brief comments on the likely effect of increased use of rainwater tanks on overall water usage in urban areas, with respect to both new and existing developments.

The Occasional paper draws conclusions, based on the reviewed available information, as follows:

- It is not possible, on the basis of existing information, to conclude whether significant health risks from chemical contaminants may be associated with regular rainwater consumption.
- Overall, the nature of the potential health risks and the importance of the different exposure routes are not intrinsically different for rainwater and conventional tap water supplies. However, given available evidence that water from rainwater tanks is more variable in both microbial and chemical quality than conventional tap supplies, it would be expected that higher risk situations would occur more frequently with rainwater supplies.
- The low number of disease outbreak reports does not necessarily rule out significant risks of illness from rainwater tanks. Passive surveillance systems are unlikely to detect small outbreaks as only a minority of people with gastrointestinal illness seek medical attention, and only a small proportion of those who do so have a faecal specimen examined for pathogens.
- Existing Australian guidelines for stored hot water temperatures appear to be adequate to inactivate enteric pathogens (note that verification that enteric pathogens are inactivated as a consequence of the time and temperature combinations used by the more recently available modes of hot water heating such as instantaneous units and solar units (under various operation modes) is required).
- Use of rainwater for toilet flushing appears to be a low risk indoor application as ingestion exposure is considered unlikely.

The review undertaken in the Occasional paper identified a number of deficiencies in the scope and quality of the available data on both microbiological and chemical water quality. Specific data gaps identified for further research in specific areas included:

- Levels of chemical contaminants in the urban Australian situation, particularly contaminants arising from urban industrial and vehicle emissions
- Variability in water quality over time in individual tanks and the relationships with rainfall patterns and environmental pollution levels
- The effects of roof and tank materials on water quality
- Systematic studies on the effect of first flush devices on water quality
- Further systematic assessment of the minimum required residence time and temperature for hot water services to reduce microbiological contamination.

2 National Survey

2.1 Objectives

The objectives of the study were based on a CRC for Water Quality and Treatment workshop held on the 24th of June 2003 and included the following:

- To review rainwater quality for various end uses in urban areas where a potable supply exists
- To gain an understanding of water quality characteristics in rainwater tanks particularly in highly urbanised areas from a physico-chemical perspective, including analysis of heavy metals, poly aromatic hydrocarbons (PAHs) and benzene-toluene-xylene (BTX) (emissions from vehicles)
- To obtain data for examination of variations in water quality over time
- To investigate the effect of climate on water quality (i.e. temperate compared with tropical Australia)
- To use the outcomes of the study to contribute to a document that underpins the installation, operation and management of rainwater tanks in the urban context.

Whilst the objectives of Stage 2 of the project were generally maintained throughout the project, climatic conditions during the project meant that the achievement of some project objectives was not possible. For example, rainwater tanks were each monitored on two occasions only. Hence, it was not possible to examine to any significant extent the variation in water quality over time. Furthermore, it was not possible to investigate the effect of climate in various localities on water quality for the same reason. Attainment of this latter objective was also hindered by the fact that rainfall events preceding monitoring at some localities were atypical given prevailing drought conditions. This disallows a comparison of rainwater tank quality between ‘usual’ temperate and tropical locality weather conditions.

2.2 Study Benefits

Likely benefits of the Stage 2 ‘Water Quality and Health Risks from Urban Rainwater Tanks’ study were identified as:

- Increased understanding of the possible health risks associated with water from rainwater tanks
- Additional baseline information on the chemical and microbiological composition of rainwater in Australian cities and urban centres which could be used to guide future studies
- Correlation between water quality and different construction materials
- Assistance in the establishment of a national protocol for the design and maintenance of rainwater tank systems used specifically for non potable purposes
- Simplification and standardisation of policies and procedures regarding the use of rainwater tanks.

2.3 Methodology

2.3.1 Rainwater tank selection and recruitment

The Cooperative Research Centre for Water Quality and Treatment's participants in the National survey were requested to find suitable rainwater tanks from which they could sample. The cities, number of tanks and participants are shown below:

Adelaide - 6 tanks (SA Water)

Brisbane - 6 tanks (Brisbane City Council)

Broken Hill - 6 tanks (NSW Health)

Canberra - 5 tanks (ACTEW)

Sydney - 6 tanks (Sydney Water Corporation)

Wollongong - 6 tanks (Sydney Water Corporation)

A concurrent study of two tanks in Melbourne will be discussed in Chapter 3. For the national survey, established rainwater tanks in urban areas with suspected chemical pollution were targeted. A document supplied to participants titled 'Requirement and Instructions', detailing how the National survey was to be undertaken, is included in Appendix 1.

The aim of the survey was to obtain an overview of the types and levels of chemical contaminants in various locations and climates. Note that sampling was to be undertaken twice, once in winter and once in summer. Also, sampling was to be undertaken just after rainfall following a dry period, as this would most likely provide the worst-case scenario.

A document titled 'List of Analytes' is attached as Appendix 2. A document titled 'Analyte Amendment List (1-6)' is also attached as Appendix 3. These documents detail the analytes to be sampled. However, not all laboratories of participants were able to test for every analyte nominated. Note - on occasions, surrogates for some analytes were supplied by laboratories.

A document titled 'Sample Collection and Handling Procedure' was developed at the commencement of the study to try to ensure that sampling was undertaken on a consistent basis throughout the country.

2.3.2 Communication

It is widely acknowledged that effective management of customer and stakeholder relationships is critical to the success of the overall project. Keeping customers and stakeholders well informed, being responsive to their concerns and making every effort to minimise inconveniences would contribute to the development of goodwill in local communities and the timely and successful delivery of the project. It was therefore important that a pro-active approach was adopted to ensure that the awareness of customers involved in the project was developed and maintained throughout the program.

Given the extent of this program it was critical that the organisations involved had a consistent approach to customer service across the nation. This did not mean the same approach but that the fundamental principles of the approaches were consistent.

The objective of the strategy was to effectively and efficiently inform the participating residents. This was achieved by:

- Adopting an issues management approach

- Communicating early with stakeholders to capture any issues and opportunities so that they could be addressed, incorporated or resolved through the early development of the project
- Being open and honest with customers about how their issues and input influenced or was integrated into the process
- Providing a structured process to facilitate stakeholder input
- Having a framework for documenting stakeholder input
- Including a methodology for determining the level of stakeholder engagement in the process.
- Developing communication tools to ensure greater consistency across stakeholders
- Establishing a single point of contact for managing communication.

Although there were few issues and concerns that may have impacted on stakeholders, the management of community issues was a key element in the rainwater tank survey communication strategy. The aim was to pre-empt or manage the issues and to eliminate or minimise any impact on customer support, trust and the reputation of the project and the organisations conducting the research on behalf of the CRC for Water Quality and Treatment. The most significant issue may have been a potential to incite health concerns with respect to the use of rainwater tanks.

Customers were initially approached to participate in the research through a phone call. Following this a letter from the CRC for Water Quality and Treatment and the participating organisation was sent to the resident giving further information and confirming any arrangements made during the phone conversation. The field officer communicated with customers and conducted the sampling following the communication protocols - see Table 2.1 and Figure 2.1. It should be noted that some organisations sampled from tanks owned by their in-house staff in order to minimise any possible issues of dealing with the general public.

Table 2.1 Communications Tools for Sampling Program

Communication Tool	Description	Purpose
Phone Call		Inform the resident of the project and obtain an agreement to participate in the project and details of arrangements for sampling.
Letters	CRC letter and Sydney Water personalised letter	To provide additional information and to confirm agreements to the participating residents and keep them informed of activities and progress of work.
Information Sheet	A fact sheet about the proposed activities and the work that is being undertaken.	To provide information to the residents about the activities during the project.
Sampling Done Calling Card	Business card with time and date of sampling with contact details for further information.	Calling card to be left for all residents not at home at the time of sampling.
Customer Assistance Card and Record of Contact Sheet		To refer the person to the designated contacts in the participating organisation and resolve any issues/ enquiries.
Letter of Introduction	Organisation letter to the resident.	To provide information to residents should they request it confirming or identifying the field worker and their role/ tasks.
Advice to Service Centre and Call Centre		Most letters that are issued to the general community regarding the work that the participating organisation is doing generally contain the name of a contact person available during business hours only. Customers may also ask questions about the work when they telephone regarding their accounts. It is essential that the call centre is aware of the project.
Results	Cover letter and table of results for a specific RWT.	To communicate the findings of the study to the resident.

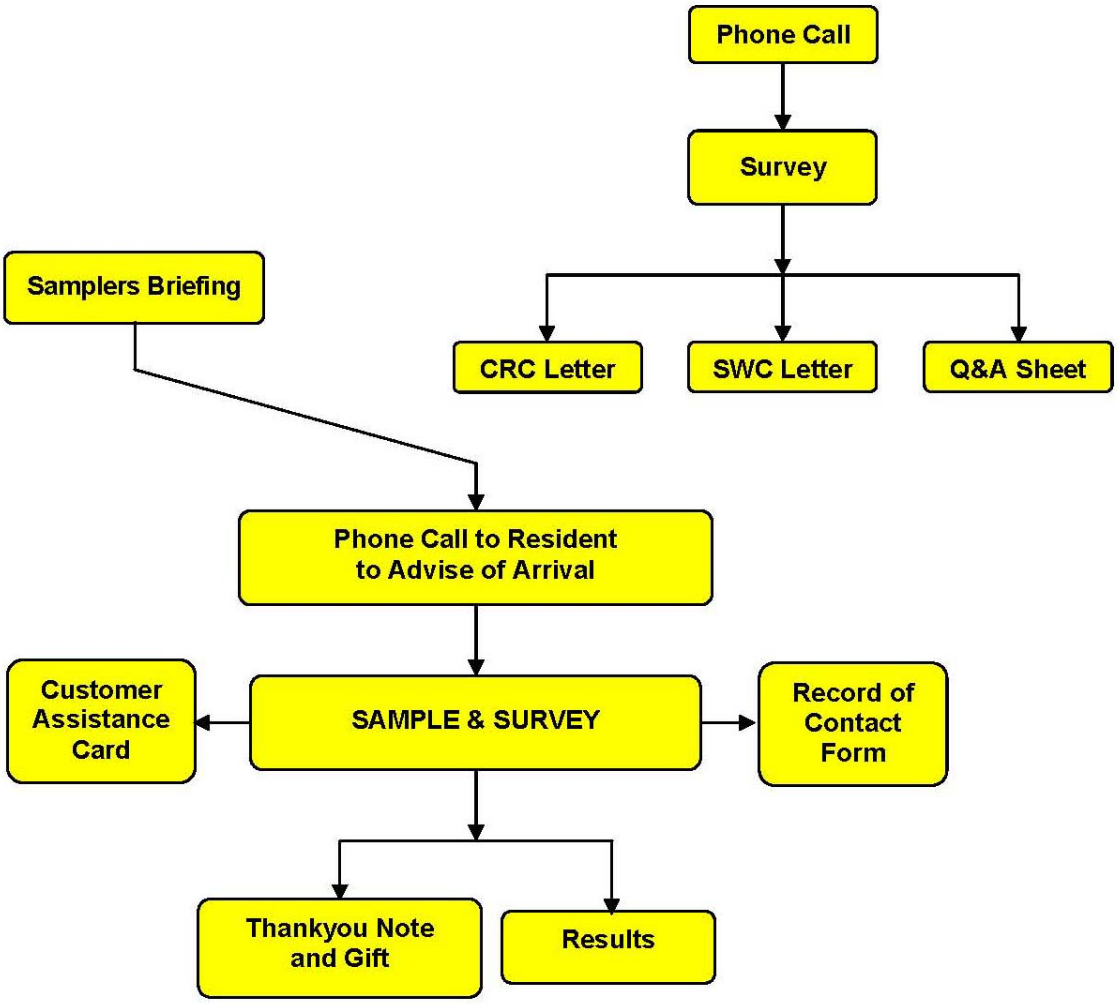


Figure 2.1 Flow Chart of Communication Activities

2.3.3 Rainwater tank characteristics

The characteristics documented for each of the rainwater tanks in the study included potential pollution sources (industry, proximity of major roads, vegetation proximity etc.), materials, age and condition of the rainwater tank and roof catchment, including guttering etc., rainwater tank capacity, end-uses and general characteristics relating to treatment etc.

2.3.4 Monitoring frequency and rainfall trigger events

The initial project objectives were to monitor rainwater tanks in each of the localities twice per year, during summer and winter following rainfall. As the project period coincided with extended drought conditions Australia wide, this was not always possible. The relationship between the two monitoring events at each locality and rainfall (mm) is given in Table 2.2.

Table 2.2 Monitoring events and rainfall data for all localities

Location	Sample	Date	Amount of rainfall on day of sampling (mm)	Amount of rainfall 24hrs prior (mm)	Amount of rainfall in week prior (mm)
Adelaide	**1**	9/9/04	4.4	14.0	27.2
	2	28/4/05	nd[1]	nd[1]	nd1[1]
Brisbane	**1**	11/1/05	0	0	13.0
	2	21/2/05	31.3	30.3	211.7
Broken Hill	**1**	16-17/8/04	0	0	0
	2	27/4/05	0	0	0
Canberra	**1**	4/8/04 & 31/8/04	2.0 31.6	7.8 20.6	7.8 20.8
	2	3/11/04	10.6	5.2	5.8
Sydney	**1**	21/10/04 & 3/11/04 (*Legionella*)	60.2	4.8	63.4
	2	16/02/05	0	0	0
Wollongong	**1**	21/10/04 & 3/11/04 (*Legionella*)	106.6	5.4	37.4
	2	16/2/05	0.2	0	1.9

[1] No data available

2.3.5 Chemical monitoring details

The number of rainwater tanks sampled and the laboratories conducting the analysis are the same for chemical analysis and microbial analysis as detailed in Table 2.3, section 2.3.6. The range of chemicals analysed at each city, the rationale for inclusion and the analytical methods employed by each laboratory for chemicals are shown in Table 2.4. Note that not all analyses were conducted by each laboratory.

2.3.6 Microbiology monitoring details

The number of rainwater tanks sampled per location and details relating to the microbiological analysis are given in Table 2.3.

Table 2.3 Microbiological monitoring details

Sampling location	No. tanks	Laboratory conducting analysis	Comments
Adelaide	6	Australian Water Quality Centre	*Legionella* detection limit <100/L Semi quantitative *Campylobacter* analysis i.e. detection limit <3/L No faecal coliform analysis
Brisbane	6	Brisbane Water Australian Laboratory Services (ALS) (pathogens)	*Legionella* detection limit <10/mL not <100/L for first round but second round <100/L No total coliform analysis No *Aeromonas* analysis
Broken Hill	6	Dept Health, NSW	Two sets of results invalid as samples 2 days old when analysed No total coliform analysis *Legionella* detection limit <100/L
Canberra	5	Ecowise (Australian Capital Territory Energy and Water - ACTEW) Australian Water Quality Centre (pathogens)	*Legionella* detection limit <100/L No faecal coliform analysis Semi quantitative *Campylobacter* analysis ie detection limit <3/L
Sydney	6	Sydney Water Silliker-Microtech (pathogens)	*Legionella* monitoring performed separately from other parameters for first run. Detection limit <100/L for first run but <10/mL for second run Qualitative *Aeromonas* analysis
Wollongong	6	Sydney Water Silliker-Microtech Pty/Ltd (pathogens)	*Legionella* monitoring performed separately from other parameters for first run Detection limit <100/L but <10/mL for second run Qualitative *Aeromonas* analysis

The selection of microbiological parameters for monitoring of rainwater tank water was made based on cost considerations, logistics (i.e. the difficulty in obtaining large volume samples and transporting them to the laboratory) and consideration of those parameters which might provide an indication of health risk associated with faecal and other (e.g. environmental) contamination of the roof catchment supplying the rainwater tank. In addition, some parameters were chosen for inclusion as indicators of the overall cleanliness of the rainwater tank and of nutrient levels in the tank water. Monitoring of tank water for protozoan pathogens, *Giardia* and *Cryptosporidium*, that may contaminate water as a consequence of bird and small animal faecal contamination of the roof catchment, was not undertaken based on the requirement for large volume samples, the infrequency of monitoring and recovery efficiency of the method (i.e. the high likelihood that even if present in the tank water they may not be detected on the two single monitoring occasions) and monitoring costs. Enteric virus sampling was not undertaken as the roof catchment supplying the rainwater tank is not subject to human faecal contamination.

Table 2.4 Rationale for the selection of microbiological parameters in the National survey

Parameter	Rationale for monitoring
E. coli	Indicator of faecal contamination of rainwater tank water. *E. coli* data is available for other rainwater tank surveys therefore can benchmark levels found against those in other studies. Gives a relatively good indication of the likely presence of enteric bacterial pathogens. Methodology simple to perform and reproducible.
Faecal coliforms	Indicator of faecal contamination of rainwater tank water although some faecal coliforms may not be of faecal origin. Faecal coliform data is available for other rainwater tank surveys therefore can benchmark levels found against those in other studies. Methodology simple to perform and reproducible.
Total coliforms	May indicate faecal contamination of rainwater tank water but may also indicate high nutrient levels and ‘regrowth’ of coliform bacteria in the tank water. Methodology simple to perform and reproducible. Some other surveys have employed total coliform monitoring hence levels in this study can be benchmarked against other studies. Total coliform levels may be obtained at no extra cost to *E. coli* levels
Enterococci	Supplementary indicator of faecal contamination of rainwater tank water. Is able to persist longer in water than *E. coli* therefore it may provide evidence of ‘remote’ faecal contamination of rainwater tank water.
Plate count	Indicator of the overall cleanliness of the rainwater tank water and of nutrient levels in the tank water. May give an indication of the amount of sediment in the tank and turnover rate of water in the tank. There is potential that concentrations of plate count bacteria may be inversely proportional to the frequency of tank cleaning or desludging the tank
C. perfringens	May be present in animal faecal matter but are also associated with environmental contamination of the water by soil etc. Used as a supplementary faecal indicator. Of most value when filtration of water is employed as they may give an indication of the effectiveness of filtration in *Cryptosporidium* removal
Aeromonas	May be used as a ‘trophic’ indicator (i.e. indicator of nutrient levels)
Campylobacter	Human bacterial enteric pathogen found in the faecal matter of birds and small animals that may have access to the roof catchment supplying the rainwater tank
Salmonella	Human bacterial enteric pathogen found in the faecal matter of birds and small animals that may have access to the roof catchment supplying the rainwater tank
Legionella spp	Opportunistic human pathogen that may arise in tank water associated with environmental contamination (e.g. soil). Potentially may proliferate in tank water if growth conditions (nutrients and temperature) are in optimum range
L. pneumophila	Opportunistic human pathogen that may arise in tank water associated with environmental contamination (e.g. soil). Potentially may proliferate in tank water if growth conditions (nutrients and temperature) are in optimum range

2.3.7 Logistics

Despite sampling and monitoring instructions being issued prior to the national survey, a common methodology was not employed for microbiological testing at all localities. This was due to the diversity of laboratories undertaking the testing, the request for some infrequently tested parameters and the inability of some laboratories to perform pathogen analysis and the need to subcontract the analysis. In addition, in some instances, the method routinely employed by the laboratory for water testing was used despite instructions to the contrary. However, all methods employed were based on internationally recognised or Australian standard methods.

2.4 Results

2.4.1 Chemistry

Water Temperature

The mean temperature and range varied for each city. As expected the lowest average temperatures were found in Canberra and Adelaide which were 12°C and 15.1°C respectively. Brisbane had the warmest average temperature with 25.5°C. The time of year when samples were taken will have a large influence on the water temperature and as only two samples were taken at different dates for each city they are not directly comparable and serve as indicators only. Broken Hill did not measure water temperatures. Average temperatures and the range for each city are given in Table 2.5 below.

Table 2.5 Mean temperature and range for each city (°C).

	Mean Temp (°C)	range
Adelaide	15.1	12 to 21
Brisbane	25.5	24 to 27
Canberra	12.0	7 to 16
Sydney	20.2	16 to 25
Wollongong	21.1	17 to 24

pH

The results of the physico-chemical analysis are presented in Table 2.6. The mean pH was 6.7 (range 3.0?-7.8) with 30% of samples below the recommended ADWG 2004 range (6.5-8.5). Adelaide had three tanks which were acidic in the first sampling and a fourth tank which was acidic (pH =3) in the second sampling. The later sample had consumed any buffering capacity in the water as evidenced by the alkalinity value of zero. All Brisbane tanks had a pH of less than 6.5 at both sample times. Broken Hill had one tank with acidic pH during the second sampling. Canberra and Sydney had several tanks with low pH with the same tanks tending to low pH at both sample times, though not consistently. A summary of the results is given in Table 2.6 and the distribution of pH values is shown in Figure 2.2. As shown, >90% of tanks had pH values of <7.5 with the greatest number of tanks between pH 7-7.5.

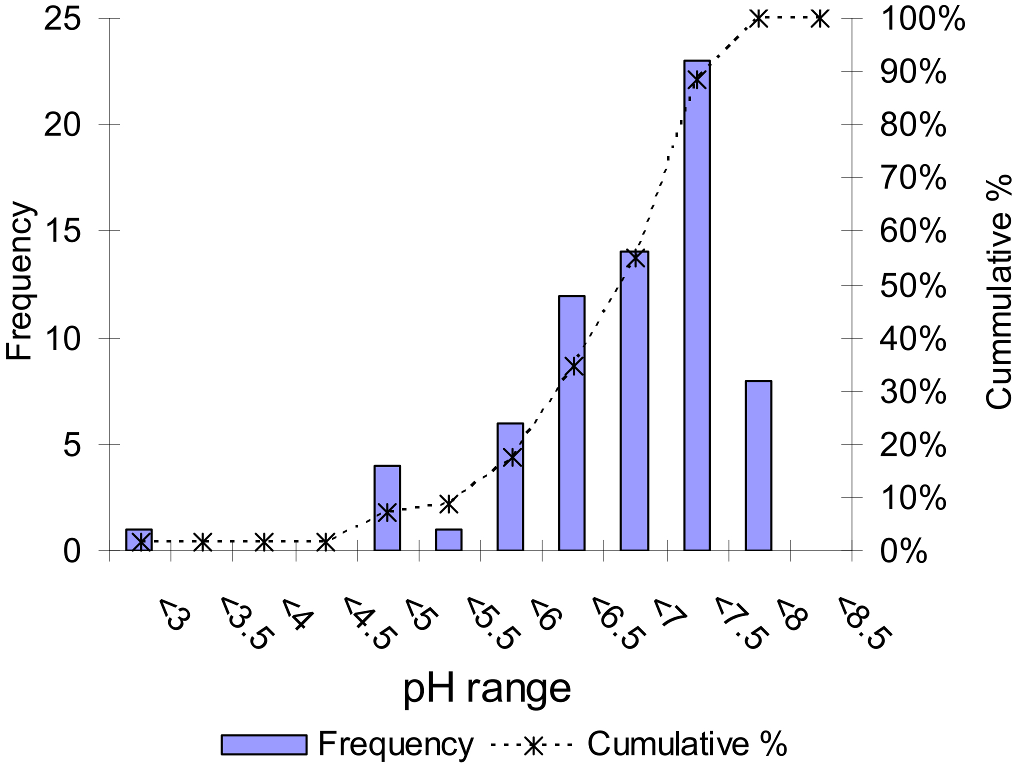


Figure 2.2 Distribution of pH values from rainwater tanks in National survey

Conductivity, total dissolved solids and total suspended solids

The conductivity of tank water samples was generally low, ranging from 6-300 µS/cm with a mean value of 51 µS/cm. For comparison, the conductivity of Brisbane municipal supply is approximately 400 µS/cm. Total dissolved solids (TDS) was accordingly low as it was measured by conductivity and the maximum value of 160mg/L was well below the aesthetic value of 500mg/L. The total suspended solids (TSS) was only measured at Broken Hill where 4 samples in the second round detected TSS with a mean value of 5.7mg/L. The second round of sampling was performed during a dry period at Broken Hill and could relate to dust in the tanks. These results are summarised in Table 2.6 below. Thus the tank water is generally soft water containing minimal salts or solids (for Hardness see Table 2.8).

Table 2.6 Alkalinity, conductivity, pH, TDS, and TSS.

	Total detected	Total tested	Mean	Standard deviation	Min	Max	ADWG*	No. samples ≥ (or ≤) to ADWG
pH	69	69	6.7	0.9	3	7.8	6.5-8.5	24 ≤ 6.5
Total Alkalinity as $CaCO_3$ (mg/L)	24	24	13.9	11.3	0	44.3		na
Conductivity (µS/cm)	69	69	51.4	50.1	6	300		na
Total Dissolved Solids (TDS) (mg/L)	58	69	33.1	28.3	9	160	500	0
Total Suspended Solids (TSS) (mg/L)	4	12	5.8	1.0	5	7		na

* Australian Drinking Water Aesthetic Guideline (2004) as no health guideline value, na = not applicable.

Turbidity, Colour and Organic Carbon

The turbidity was generally low in all tanks with a maximum value of 3.8 NTU, which is below the ADWG aesthetic value of 5 NTU. True color did exceed the ADWG aesthetic value in one tank in Brisbane for both samples and one tank in Broken Hill for both samples (7% samples). The Broken Hill tank with high true colour was fed by a 50 year old painted zincalume roof in fair condition with a 20L first flush fitted to a polypropylene tank and trees within 5m or more of the roof. Twenty eight percent of samples had true color below the detection limit. Total organic carbon (TOC) averaged 1.5 mg/L, most of which was dissolved organic carbon (DOC). The summarised results are presented in Table 2.7 below.

Table 2.7 Turbidity, Colour and Organic Carbon

	Total detected	Total tested	Mean	Min	Max	ADWG*	Units
Turbidity	69	69	1.0	0.14	3.8	5	NTU
True Colour	44	59	6.7	0.5	80	15	HU
Apparent Colour	6	6	11.5	4.7	35.3	none	HU
TOC	47	57	1.5	0.2	16	none	mg/L
DOC	49	57	1.3	0.2	11	none	mg/L

* Australian Drinking Water Aesthetic Guideline (2004) as no health guideline value. TOC = Total organic carbon, DOC = Dissolved organic carbon.

Ionic composition and nitrogen compounds

Nitrogen was present in all tanks at low levels in the form of ammonia and nitrate, with the more toxic nitrite detectable at 6µg/L in only one of 12 samples from 6 tanks in Adelaide. All nitrogen compounds were below the ADWG (2004). The presence of nitrate, but usually no nitrite, indicates an oxidizing environment in most tanks. The ammonia present is possibly from degradation of organic matter in the tank. The tank water was soft in all samples with the maximum hardness value below the recommended minimum of 60mg/L as $CaCO_3$. This corresponds with the low levels of cations and anions seen in tank water samples. Sulphate and Nitrate ions are often linked to industrial emissions and a low pH (Aherne and Farrell, 2002; Ayers *et al.* 2002) though no relationship was seen in the National survey data as shown in Figure 2.3 below. The results summary for cations, anions and nitrogen compounds is presented in Table 2.8 below.

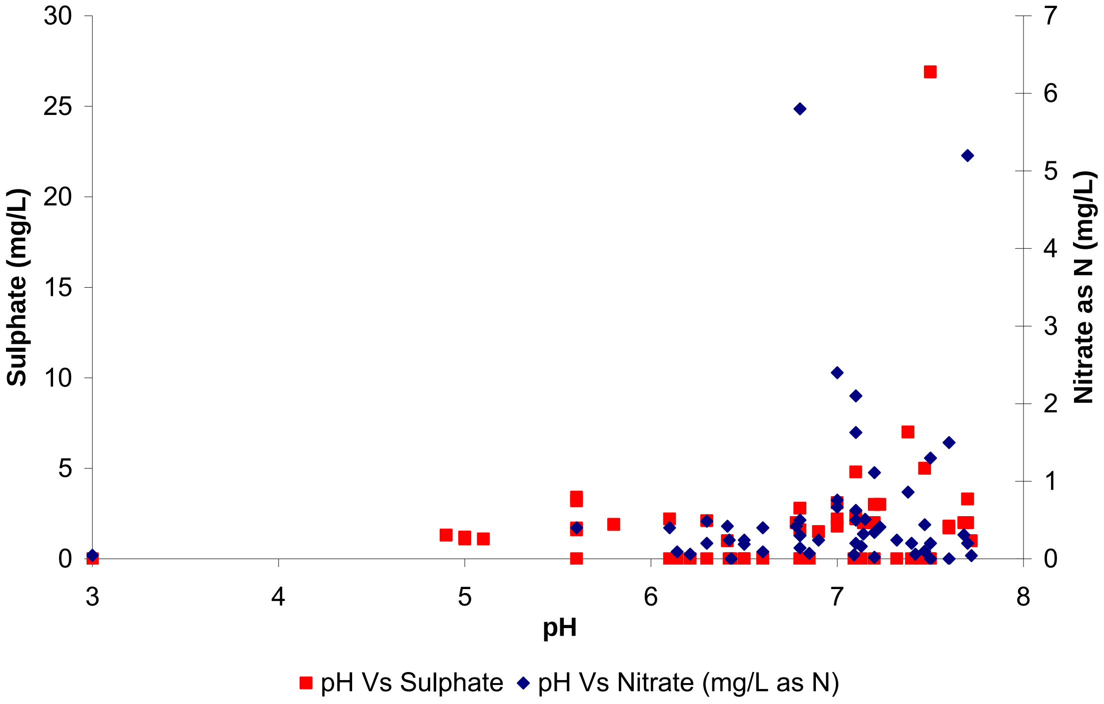


Figure 2.3 Sulphate and nitrate ion concentrations Vs pH

Table 2.8 Ionic composition, hardness and nitrogen compounds

Ion (mg/L)	Total detected	Total tested (N)	Mean	Standard deviation	Min	Max	ADWG Health	ADWG Aesthetic	no. ≥ (or ≤) to ADWG
Calcium	60	69	3.7	3.8	0.186	18			
Magnesium	56	69	0.6	0.7	0.07	5.05			
Potassium	41	59	0.6	0.7	0.09	3.4			
Sodium	57	59	3.5	3.1	0.61	19.7		180	0
Bicarbonate	12	12	20.9	17.1	0	54			
Sulphate	42	69	3.2	4.3	1	26.9	500	250	0
Hardness as $CaCO_3$	60	69	11.6	10.8	0.7	51.9		60-200	60
Nitrite (as N)	1	12	0.006	na	0.006	0.006	0.91		0
Nitrate (as N)	55	58	1.2	1.9	0.02	7.6	11.2		0
Ammonia (as N)	37	44	0.074	0.084	0.002	0.270		0.41	0

Pesticides, fungicides and herbicides

A range of pesticides, herbicides, fungicides and pyrethroids were screened. Each laboratory tended to test for their own suite of chemicals, which led to only partial consistency between laboratories. Of the range of chemicals tested for, there was only one tank from the second sampling in Brisbane that detected the herbicide CPA (4-chlorophenoxy acetic acid) at a level of 366µg/L in tank water. The same tank did not have any present in the first round of testing. Brisbane was the only location that tested for CPA so this result is one of eleven samples in total that were tested for CPA. All other samples from all locations did not detect any chemicals in this class. It is worth noting that some sample sizes are as small as 6 as they were only tested in one location for one sample run. No statistical analysis is attempted due to the small sample sizes.

Hydrocarbons and volatile organic compounds

Sydney and Wollongong were the only laboratories which tested for general hydrocarbons. Of these samples there were two tanks in Wollongong in the second sampling in which hydrocarbons were detected in the C15-C28 carbon length range at concentrations of 0.4 and 0.1 mg/L, while in all other samples no hydrocarbons were detected. No BTEX compounds were detected in any samples, though not all laboratories tested for all compounds as indicated by the variation in numbers tested given in Table 2.9 below.

Table 2.9 Results of testing for Hydrocarbons and Volatile organics

Class	Compound(s)	Total detected	Total tested (N)	Mean	Min	Max
HYDROCARBONS (mg/L)	TPH C6-C9	0	24			
	TPH C10-C14	0	24			
	TPH C15-C28	2	24	0.3	0.1	0.4
	TPH C29-C36	0	24			
VOLATILE ORGANICS - BTEX (µg/L)	Ethyl benzene	0	57			
	o-Xylene (ortho-xylene)	0	57			
	meta-xylene	0	6			
	(m+p)-Xylenes	0	41			
	Toluene	0	57			
	Benzene	0	57			
	1,3,4-trimethylbenzene (1,2,4-trimethylbenzene)	0	6			
	1,3,5-trimethylbenzene	0	6			
	Chlorobenzene	0	6			
	Total BTEX	0	12			

Phthalates

Brisbane, Canberra and only the second sampling for Sydney and Wollongong tested for a range of phthalates which totaled 34 samples. Only two tanks (6%) in the second sampling in Canberra detected bis(2-ethylhexyl)Phthalate in two tanks at concentrations of 47µg/L and 310µg/L for which there are no guidelines. An ADWG guideline of 10 µg/L ADWG value is set for di(2-ethylhexyl) phthalate and di(2-ethylhexyl) adipate. Personal discussions with some laboratories revealed that due to the ubiquitous nature of phthalates this result may indicate that the levels found in the tank water are not above the background levels found in analytical blanks. Completely uncontaminated analytical blanks are often difficult to achieve in practice. The results for phthalates are summarised in Table 2.10 below.

Table 2.10 Results of testing for Phthalates

Compound	Total detected	Total tested	Mean (µg/L)	Min (µg/L)	Max (µg/L)
Dimethyl phthalate	0	34			
Diethylphthalate	0	34			
Dibutylphthalate	0	34			
Butyl benzyl phthalate	0	33			
Bis(2-ethylhexyl)Phthalate	2	34	179	47	310
Di-n-Octylphthalate	0	33			

Disinfection by products

In samples tested for disinfection by products (DBPs) none were detected. This is consistent with the lack of chlorination or ozone disinfection in most tanks which are the primary sources of these compounds. The use of these disinfection procedures with the presence of bromine or organic matter (the latter being present in most tanks; see Table 2.7), has the potential to form DBPs and this must be kept in mind for any recommendations aimed at improving the microbiological quality of the water. The DBP's tested for and number of samples tested is shown in Table 2.11 below. Total trihalomethanes was only tested for in Adelaide while Brisbane and Canberra did not test for any DBP's.

Table 2.11 Results of testing for Disinfection by-products

Compound	Total detected	Total tested
Bromoform	0	48
Bromodichloromethane	0	48
Chlorodibromomethane	0	48
Chloroform	0	48
Total Trihalomethanes	0	12

Phenolics

Adelaide, Sydney and Wollongong tested for phenolic compounds, though Adelaide tested for a different suite than Sydney and Wollongong, with only partial overlap of compounds. This is reflected in the variable numbers tested as shown in Table 2.12. When the total number tested equals 36 it indicates that the compound was tested in all three locations for both sample times. Of the samples tested no phenolic compounds were detected in any tanks.

Table2.12 Results of testing for Phenolic compounds

Compound	Total detected	Total tested
2-bromophenol	0	12
3-bromophenol	0	12
4-bromophenol	0	12
2,4-dibromophenol	0	12
2,6-dibromophenol	0	12
2,4,6-tribromophenol	0	12
2-chlorophenol	0	36
4-chlorophenol	0	12
2,4-dichlorophenol	0	36
2,6-dichlorophenol	0	36
3,5-dichlorophenol	0	12
2,3,4,6-tetrachlorophenol	0	24
2,4,5-trichlorophenol	0	36
2,4,6-trichlorophenol	0	36
2,4-dimethylphenol	0	24
2-methylphenol	0	24
3-methylphenol	0	24
4-chloro-3-methylphenol	0	24
4-methylphenol	0	24
Pentachlorophenol	0	36
Phenol	0	24

Polycyclic Aromatic Hydrocarbons (PAHs)

A range of PAH compounds were tested (Table 2.13). Adelaide and Broken Hill did not test for PAHs. Of the 45 samples from the 23 tanks tested no PAHs were detected. Detection limits for PAH compounds were 0.1-0.2 µg/L for most laboratories excluding Brisbane where the detection limit was given as 0.5 µg/L. This is above the 0.01 µg/L guideline value given in the 2004 ADWG and as such no conclusions on the health aspects can be drawn from this except that PAHs are not present in very high levels.

Table 2.13 Polycyclic Aromatic Hydrocarbon testing results.

Compound (µg/L)	Total tested (N)	Total detected*
Total Detectable PAH	34	0
Acenapthene	45	0
Anthracene	45	0
Benzo(a)anthracene	45	0
Benzo(a)pyrene	45	0
Benzo(b)fluoranthene	45	0
Benzo(e)pyrene	30	0
Benzo(ghi)perylene	45	0
Benzo(k)fluoranthene	45	0
Chrysene	45	0
Dibenzo(a,h)anthracene	45	0
Fluoranthene	45	0
Fluorene	45	0
Indeno(1,2,3-cd)pyrene	45	0
Naphthalene	45	0
Phenanthrene	45	0
Pyrene	45	0
Acenaphthylene	45	0

* detection limit = 0.1-0.5µg/L, 2004 ADWG Benzo-(a)-pyrene = 0.01 µg/L

Trace metals

The summary of results for trace metal analysis are presented in Table 2.14. Not all trace metals have ADWG concentrations set, however of the metals where a guideline level is given, only lead, zinc and one sample for total aluminium equaled or exceeded the ADWG (2004) for health or aesthetics. Of these the main health concern is lead. Lead was detected in 79% of tanks, with six tanks (9%) having levels equal to or exceeding the ADWG (2004). The high lead values originated from one tank each in Brisbane and Canberra, two samples from the same tank in Wollongong and two samples from different tanks in Broken Hill. Zinc levels of greater than 3mg/L were found in seven samples from Adelaide, of which five are from the second sample round, and two from each round of sampling in Broken Hill, both from the same tanks (total=4). 3mg/L is the aesthetic ADWG (2004) level for zinc and is associated with taste but not health problems. One sample from Adelaide had total aluminium of 241µg/L which is above the ADWG aesthetic value for soluble aluminium. This guideline level is based on post-flocculation problems and not health. Furthermore, soluble aluminium was not detected in this sample and hence aluminium is not of concern from this data. All other trace metal levels were below the ADWG (2004) health and aesthetic values.

Table2.14 Results of testing for trace metals

	Total detected	Total tested	**Mean**	Standard deviation	Min	Max	ADWG Health	ADWG aesthetic	Units	no. samples ≥ to ADWG
Aluminium (soluble)	0	12	na	na	0	0		200	µg/L (acid soluble)	
Total Aluminium	54	69	41.6	36.2	10	241			µg/L	1
Arsenic	3	27	1.0	0.0	1	1	7		µg/L	0
Antimony	0	16	na	na	0	0	3		µg/L	0
Barium	14	21	6.4	3.9	2.4	18	700		µg/L	0
Beryllium	0	10	na	na	0	0				
Cadmium	8	69	0.9	0.3	0.6	1.4	2		µg/L	0
Total Chromium	4	69	9.8	9.7	2	23	50[1]		µg/L	0
Cobalt	1	58	0.7	na	0.7	0.7				
Total Copper	60	69	18.4	38.6	1	220	2000	1000	µg/L	0
Total Iron	44	69	44.8	46.7	10	181		300	µg/L	
Total Lead	53	69	3.8	3.3	0.3	13[2]	10		µg/L	6
Total Lithium	2	44	3.5	0.7	3	4			µg/L	
Manganese	67	69	10.2	10.7	0.5	53	500	100	µg/L	0
Molybdenum	0	16	na	na	0	0	50		µg/L	0
Total Mercury	1	45	0.4	na	0.4	0.4	1		µg/L	0
Total Nickel	18	69	2.0	1.3	0.5	5	20		µg/L	0
Selenium	0	16	na	na	0	0	10		µg/L	0
Silver	0	16	na	na	0	0	100		µg/L	0
Strontium	46	48	15.2	19.7	2	90				
Total Tin	0	24	na	na	0	0				
Total Zinc	69	69	1790	3099	12	13400[3]		3000	µg/L	11

[1] as CrVI,

[2] exceeds the ADWG 2004 health value,

[3] exceeds the ADWG 2004 aesthetic values.

2.4.2 Microbiology

Summary results for each of the urban localities where tank water quality monitoring was performed are presented separately below (Table 2.15 – Table 2.21). Presentation of data according to locality is performed to allow results to be compared, within limitations (based on the limited number of samples monitored), in the context of climate variation between localities. In addition, treatment of data according to locality allows longitudinal data for individual tanks within a locality to be examined in the context of the amount of rainfall occurring prior to monitoring.

An overall summary of results according to parameter (Table 2.21) is also presented with results from all localities pooled together to allow a snapshot of overall prevalence rates for each micro-organism to be obtained.

Summary descriptive statistics chosen for microbiological water quality results are percentage prevalence, range (minimum value – maximum value) and median. These summary statistics have been selected as a consequence of low number of samples analysed and/or the predominance of ‘non detections’ of some micro-organisms in water samples.

Location: Adelaide

Six rainwater tanks were monitored twice for microbiological parameters. A summary of the results for Adelaide is given in Table 2.15. Overall, results for Adelaide rainwater tanks show high prevalence rates for total coliforms (67%), and enterococci (73%). The presence of these bacteria is consistent with faecal contamination of tank water and/or environmental contamination arising from soil, vegetation etc. The presence of *E. coli* indicator bacteria in 42% of samples indicates recent faecal contamination of a significant proportion of tank waters and the possible presence of pathogens in these waters. Nonetheless, *Campylobacter* was not detected in any of the analysed samples. However, *Salmonella* was detected in one tank on the first monitoring occasion. The amount of rain detected in the 24hrs preceding the monitoring event was 14.0mm. *Salmonella* was not detected in this same tank on the second monitoring occasion.

An overall high median plate count of 9,900 orgs/mL was obtained with counts ranging from 140 – 72,000 orgs/mL for individual samples. *Legionella* was detected in two rainwater tanks samples. For one rainwater tank sample the number of *Legionella* species detected was at the limit of detection (100 orgs/L). For the other rainwater tank sample, *Legionella* spp counts were 840,000 orgs/L. *Legionella pneumophila* bacteria were not detected in any samples.

Table 2.15 Summary of microbiological results for rainwater tanks, Adelaide

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	42%	12	0	0-250
Faecal coliforms/100mL				Not tested for
Total coliforms/100mL	67%	12	100	0-2000
Enterococci/ 100mL	73%	12	100	0-450
Plate count (35^{o}C/48hr)	100%	12	9900	140-72000
C. perfringens/100mL	8%	12	0	0-1
Aeromonas spp/100mL	33%	12	0	0-1700
Campylobacter spp/L*	0%	12	NA	NA
Salmonella spp/L	8%	12		
Legionella spp/L	17%	12	<100	<100-840,000
L. pneumophila/L	0%	12	NA	NA

* semi quantitative i.e. MPN resolution <3orgs/L

Location: Brisbane

Six rainwater tanks were monitored for microbiological parameters. With the exception of one tank, samples were collected from each tank on two occasions. A summary of the results for Brisbane is given in Table 2.16. *E. coli* and/or faecal coliforms were detected in all tanks on the first monitoring occasion but not on the second. No rainfall was recorded in the 24hrs prior to the first monitoring occasion (total for the week prior to the first monitoring occasion was 13.0mm). This compares with 30.3 mm rainfall in the 24 hrs prior to the second monitoring (211.7 mm in the week prior). Despite low rainfall prior to the first monitoring, high numbers of *E. coli* (260orgs/100mL) and faecal coliforms (420orgs/100mL) were detected in one of the Brisbane tanks (BRI-6).

While it is expected that higher rainfall might lead to higher levels of faecal bacteria in tank water, the number of faecal bacteria gaining entry to the tank is dependent upon the presence of faecal matter on the roof catchment prior to the rainfall event. These results may simply reflect the fact that on the second monitoring occasion there was an absence of faecal matter on the roof prior to monitoring leading to an absence of input of 'fresh' faecal matter into the tank despite relatively a high water volume entering the tank.

Overall, results for Brisbane rainwater tanks show high prevalence rates for faecal coliforms (73%), *C. perfringens* (91%) and enterococci (70%). The presence of these bacteria is consistent with faecal contamination of tank water and/or environmental contamination arising from soil, vegetation etc. The presence of *E. coli* indicator bacteria in 36% of samples indicates recent faecal contamination of a significant proportion of tank waters and the possible presence of pathogens in these waters. Nonetheless, enteric bacterial pathogens, *Salmonella* and *Campylobacter* were not detected in any of the analysed samples, including in rainwater tank BRI-6 on the first monitoring occasion. High numbers of plate count bacteria were noted in all samples with a median count of 12,000 orgs/mL recorded overall. *Legionella* bacteria (detection limit <10/mL for first monitoring occasion and <100 orgs/L for the second monitoring occasion) were not detected in any of the rainwater tanks on both monitoring occasions.

Table 2.16 Summary of microbiological results for rainwater tanks, Brisbane

Parameter	% Prevalence	N	Median	Range
E. coli /100mL	36%	11	0	0-260
Faecal coliforms/100mL	73%%	11	2	0-420
Total coliforms/100mL	Not tested for			
Enterococci/ 100mL	70%	11	3	0-19
Plate count (35°C/48hr)	100%	11	12,000	1,900-60,000
C. perfringens/100mL	91%	11	4	0-55
Aeromonas spp/100mL	Not tested for			
*Campylobacter spp/*L	0%	11	NA	Qualitative Presence/Absence
Salmonella spp/L	0%	11	NA	Qualitative Presence/Absence
Legionella spp/mL	0%	6	<10/mL	NA
Legionella spp/L	0%	5	<100/L	NA
L. pneumophila/mL	0%	6	<10/mL	NA
L. pneumophila/L	0%	5	<100/L	NA

Location: Broken Hill

Six rainwater tanks were monitored twice for microbiological parameters. A summary of the results for Broken Hill is given in Table 2.17. Two rainwater tank samples collected on the first monitoring occasion were greater than 24hrs old when analysed by the laboratory. Results for these samples have not been included in summary results in Table 2.17 as the extended time interval between sample collection and sample analysis may have given rise to bacterial die-off or re-growth in the sample. Nonetheless, there is little impact of the removal of results for these samples on the overall summary prevalence rates or median counts.

Of note is the absence of *E. coli* in all rainwater tank waters. The high prevalence rates for enterococci (70%) and *C. perfringens* (70%) however are consistent with past faecal contamination of a high proportion of rainwater tank waters. Enteric pathogens, *Salmonella* and *Campylobacter* were not detected in any rainwater samples. No rainfall was recorded in the week prior to either the first or second monitoring occasion.

A median plate count of 7100 orgs/mL and range of 110-130,000 orgs/mL was recorded for water samples overall. *Legionella* species other than *Legionella pneumophila* were detected in 70% of rainwater samples. *Legionella* counts for positive samples ranged from 100 – 73,000 orgs/L (detection limit <100 orgs/L).

Table 2.17 Summary of microbiological results for rainwater tanks, Broken Hill

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	0%	10	NA	NA
Faecal coliforms/100mL	0%	6	NA	NA
Total coliforms/100mL	Not determined			
Enterococci/ 100mL	70%	10	4	0-37
Plate count (35°C/48hr)	100%	10	7100	110-130,000
C. perfringens/100mL	70%	10	2	0-16
Aeromonas spp/100mL	10%	10	0	0-22
Campylobacter spp/L	0%	10	NA	NA
Salmonella spp/L	0%	10	NA	NA
Legionella spp/L	70%	10	850	<100-73,000
L. pneumophila/L	0%	10	NA	NA

Location: Canberra

Five rainwater tanks were monitored twice for microbiological parameters. A summary of the results for Canberra is given in Table 2.18. Very high numbers of *E. coli* (9200 orgs/100mL) were detected in rainwater tank RA 1002 on the second monitoring occasion. Corresponding high numbers of total coliforms (48,000 orgs /100mL) and enterococci (32,000 orgs/100mL) were also detected in this sample. These levels of indicator bacteria indicate recent faecal contamination of tank water and levels are similar to those found in significantly faecally polluted untreated surface water. Whilst the enteric pathogen *Salmonella* was not detected, *Campylobacter* (43orgs/L) was detected in this rainwater sample. On the first occasion rainwater tank RA 1002 was monitored, *E. coli* bacteria were not detected but enterococci (65orgs/100mL) and total coliforms (2000 orgs/100mL) were detected indicating possible remote faecal contamination. For the first monitoring, 31.6 mm rainfall was recorded on the day of sampling and 20.8 mm in the week prior to sampling. For the second monitoring 10.6mm rainfall was recorded on the day of sampling and 5.8mm in the week prior to sampling.

Overall, results for Canberra rainwater tanks show high prevalence rates for total coliforms (100%) and enterococci (100%). The presence of these bacteria is consistent with faecal contamination of tank water and/or environmental contamination arising from soil, vegetation etc. The presence of *E. coli* indicator bacteria in 50% of samples indicates recent faecal contamination of a significant proportion of tank waters and the possible presence of pathogens in these tank waters. A median plate count of 2400 orgs/mL and range of 87-20,000 orgs/mL was recorded for water samples overall. *Legionella* was detected in rainwater tank 1001 on the first, but not the second monitoring occasion. The number detected was 20,000 organisms per L (detection limit <100 orgs/L).

Table 2.18 Summary of microbiological results for rainwater tanks, Canberra

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	50%	10	5	0-9200
Faecal coliforms/100mL				Not tested for
Total coliforms/100mL	100%	10	220	6-48,000
Enterococci/ 100mL	100%	10	67	1-32,000
Plate count (35°C/48hr)	100%	10	2400	87-20,000
C. perfringens/100mL	50%	10	2	0-120
Aeromonas spp/100mL	60%	10	121	0-38,000
Campylobacter spp/L*	10%	10	<3	<3-43
Salmonella spp/L	0%	10	NA	Qualitative: P/A
Legionella spp/L	10%	10	<100	<100-20,000
L. pneumophila/L	0%	10	NA	NA

* semi quantitative i.e. MPN resolution <3orgs/L

Location: Sydney

Six rainwater tanks were monitored twice for microbiological parameters. A summary of the results for Sydney is given in Table 2.19. *E. coli* was detected in all rainwater tanks on both monitoring occasions with an overall median count of 64 orgs/100mL (Range 1-3900 orgs/100mL). Corresponding median total coliform and enterococci counts overall were 340 and 199 orgs/100mL respectively. The presence of *E. coli* indicator bacteria in all samples indicates recent faecal contamination of rainwater tank waters and the possible presence of pathogens in these waters. *E. coli* counts in excess of 100 orgs/100mL were recorded for 4/12 samples. Despite the presence of *E. coli* in all samples and *E. coli* counts at some sites in excess of 1000 orgs/100mL, enteric pathogens, *Salmonella* and *Campylobacter* were not detected on either monitoring occasion. Significantly higher *E. coli*, total coliforms and enterococci counts were obtained in rainwater tank SY-4 on the second monitoring, as compared with the first. For the first monitoring, 60.2 mm rainfall was recorded on the day of sampling and 63.4 mm in the week prior. For the second monitoring no rainfall was recorded on the day of sampling or in the week before.

A median plate count of 23,000 orgs/mL and range of 820-57,000 orgs/mL was recorded for water samples overall. *Legionella* was not detected in any rainwater tank samples. A *Legionella* detection limit of 0.1 organisms/mL (equivalent to 100organisms/L) was applied for the first monitoring event and a detection limit of 10 organisms /mL for the second monitoring event. Overall prevalence rates for *Aeromonas* and *C. perfringens* were 25% and 33% respectively.

Table 2.19 Summary of microbiological results for rainwater tanks, Sydney

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	100%	12	64	1-3900
Faecal coliforms/100mL	100%	12	64	1-3900
Total coliforms/100mL	100%	12	340	6-5400
Enterococci/ 100mL	100%	12	199	46-710
Plate count (35oC/48hr)	100%	12	23,000	820-57,000
C. perfringens/100mL	33%	12	0	0-16
Aeromonas spp/100mL	25%	12	NA	Qualitative Presence/Absence
Campylobacter spp/L	0%	12	NA	Qualitative Presence/Absence
Salmonella spp/L	0%	12	NA	Qualitative Presence/Absence
Legionella spp/L	0%	6	<100	NA
*Legionella spp/*mL	0%	6	<10	NA
L. pneumophila/L	0%	6	<100	NA
*L. pneumophila/*mL	0%		<10	NA

Note EC count used for FC where FC<EC

Location: Wollongong

Six rainwater tanks were monitored twice for microbiological parameters. A summary of the results for Wollongong is given in Table 2.20. *E. coli* was detected in all rainwater tanks on both monitoring occasions with an overall median count of 123 orgs/100mL (range 1-6100/100mL). Corresponding median total coliform and enterococci counts overall were 405 and 305 orgs/100mL respectively. The presence of *E. coli* indicator bacteria in all samples indicates recent faecal contamination of rainwater tank waters and the possible presence of pathogens in these tank waters. *E. coli* counts in excess of 100 orgs/100mL were recorded for 6/12 samples. The enteric pathogen *Campylobacter* was not detected in any rainwater tank water on either monitoring occasion, however, *Salmonella* was detected in WG-8 on the second monitoring occasion (corresponding *E. coli* count was 7 organisms/100mL). Significantly higher *E. coli*, total coliforms and enterococci counts were detected in rainwater tank WG-13 on the second monitoring occasion. For the first monitoring, 106.4 mm rainfall was recorded on the day of sampling and 37.4 mm in the week prior to sampling. For the second monitoring, 0.2mm rainfall was recorded on the day of sampling and 1.9mm in the week prior to sampling.

A median plate count of 18,000 orgs/mL and range of 780-57,000 orgs/mL was recorded for water samples overall. *Legionella* was not detected in any rainwater tank samples. A *Legionella* detection limit of 0.1 organisms/mL (equivalent to 100organisms/L) was applied for the first monitoring event and a detection limit of 10 organisms /mL for the second monitoring event. Overall prevalence rates for *Aeromonas* and *C. perfringens* were 33% and 42% respectively.

Table 2.20 Summary of microbiological results for rainwater tanks, Wollongong

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	100%	12	123	1-6,100
Faecal coliforms/100mL	100%	12	260	2-7,500
Total coliforms/100mL	100%	12	405	4-30,000
Enterococci/ 100mL	92%	12	305	0-5,000
Plate count (35°C/48hr)	100%	12	17,500	780-57,000
C. perfringens/100mL	42%	12	0	0-27
Aeromonas spp/100mL	33%	12	NA	Qualitative
Campylobacter spp/L	0%	12	NA	Qualitative
Salmonella spp/L	8%	12	NA	Qualitative
Legionella spp/L	0%	6	<100	NA
Legionella spp/mL	0%	6	<10	NA
L. pneumophila/L	0%	6	<100	NA
	0%	6	<10	NA

Note EC count used for FC where FC<EC

Overall Analysis

A total of 67 samples from 35 rainwater tanks at 6 localities were monitored for microbiological parameters. Summary statistics for each microbiological parameter are given in Table 2.21 below.

Table 2.21 Summary of microbiological results for all rainwater tanks, National survey

Parameter	% Prevalence	N*	Median	Range
E. coli /100mL	57%	67	2	0-9,200
Faecal coliforms/100mL	78%	41	17	0-7,500
Total coliforms/100mL	91%	46	260	0-48,000
Enterococci/ 100mL	82%	67	61	0-32,000
Plate count (35°C/48hr)	100%	67	9700	87-130,000
C. perfringens/100mL	49%	67	0	0-120
Aeromonas/100mL	32%	56	0	0-38,000
Campylobacter/L	1.5%	67	0	<1-43
Salmonella/L	3%	67	0	P/A only
Legionella spp/L	20%	49	<100	<100-840,000
Legionella spp/mL	0%	18	<10	NA
Overall *Legionella spp* prevalence/L	15%	67	<100	<100-840,000
L. pneumophila/L	0%	49	<100	NA
L. pneumophila/mL	0%	18	<10	NA

Note: *Data for tanks where samples were 2 days old when analysed are omitted from above table

Indicator counts

Prevalence results (see Table 2.21) for all surveyed tanks show that there is an overall high prevalence rate of faecal indicator bacteria: *E. coli* (57%), total coliforms (91%) and enterococci (83%). These results are not surprising, given the general susceptibility of the rainwater roof catchments to faecal contamination from birds and small animals, and are in accord with results from other rainwater tank surveys (Bannister, Westwood et al. 1997; Coombes, Kuczera et al. 2000; Albrechtsen 2002; Savill, Hudson et al. 2001; Simmons, Hope et al. 2001).

Overall prevalence rates for *Aeromonas* (32%) and *C. perfringens* (49%) are consistent with potential faecal contamination, environmental contamination (e.g. from soil and vegetation) and/or bacterial regrowth in rainwater tank water.

Summary total coliform, *E. coli* and enterococci counts (see Table 2.22) for the pooled results for the 6 localities highlight the variability in the degree of faecal and other contamination of rainwater that may occur both spatially and temporally. Overall high median numbers of heterotrophic plate count bacteria (9700 orgs/mL), as compared with conventional tap water supplies, are consistent with low turnover of water and /or the build up of sediment supplying nutrients on which bacteria may grow and multiply.

Pathogens

Prevalence results for pathogens (see Table 2.21) show that the enteric bacterial pathogen, *Campylobacter* was detected in one out of the 35 (3.0%) rainwater tanks corresponding to one out of 67 (1.5%) samples analysed. Of note is that bacterial indicator results for this sample were of a magnitude consistent with highly faecally polluted raw surface water (*E. coli* count of 9200 orgs/100mL). A Most Probable Number (MPN) method employed to enumerate *Campylobacter*, calculated 43 organisms per Litre.

The *Campylobacter* prevalence rate reported for the National survey falls between rates reported for other rainwater studies. For example, reported prevalence rates were 38% for one New Zealand study where *Campylobacter* species were detected in 9 out of 24 rainwater tanks surveyed (Savill, Hudson et al. 2001) and no positive detections for *Campylobacter jejuni* for another New Zealand study where 125 rainwater tanks were surveyed (Simmons, Hope et al. 2001). Both New Zealand studies were undertaken in rural areas. Other studies reported *Campylobacter jejuni* prevalence rates of 12% in surveyed rainwater tanks in Denmark (Albrechtsen 2002) and *Campylobacter* species prevalence rates of 23% in tanks surveyed in rural Victoria, Australia (Bannister, Westwood et al. 1997). Enumeration of *Campylobacter* was not performed in all studies and a variety of sample volumes were examined or sample volumes were not stated. No speciation of detected *Campylobacter* was performed in this study.

The enteric bacterial pathogen, *Salmonella* spp was detected in two out of the 35 (6%) rainwater tanks corresponding to two out of 67 (3.0%) samples analysed. On the two occasions that *Salmonella* spp were detected, corresponding *E .coli* counts in tank waters were 12 and 7 organisms per 100mL respectively. Documented prevalence rate for *Salmonella* in rainwater tanks are 0.9% in rural New Zealand (Simmons, Hope et al. 2001) and an absence of *Salmonella* in 5 rainwater tanks in a Victorian rural town (Thurman, 1995).

Legionella species were detected in eight out of thirty five (23%) rainwater tanks and 10 out of 67 (15%) samples, as *Legionella* was detected in some tanks on two occasions. Of note however is that two detection limits were used for the analysis. Overall, out of a total of 67 samples analysed for *Legionella,* a detection limit of <10orgs/mL was applied to 18 samples and a detection limit of <100orgs/L or <0.1/mL was applied to 49 samples. No *Legionella* species were detected at the less sensitive detection limit. The range of *Legionella* species in positive samples using the more sensitive detection method ranged from 100 – 840,000 orgs/L. (equivalent to 0.1 - 840 orgs/mL)*. Legionella pneumophila* (serogroup 1 and 2-14) was not detected in any rainwater tank sample.

These results are not incompatible with those reported in the literature. One study of rainwater cisterns in the Virgin Islands detected *Legionella* in a high proportion of samples (Broadhead, Negron-Alvira et al. 1988). In contrast to the positive *Legionella* detections in the Virgin Islands' tanks, a New Zealand study of 125 tanks failed to isolate *Legionella* species from any of the tanks (Simmons, Hope et al. 2001). In the New Zealand study the reported detection method was AS3896-1991, a similar method to that employed in this survey (AS/NZS 3896-1998). This method has a general detection limit of <10 organisms per mL where a preamble concentration step is not performed. Hence, a greater prevalence rate may have been observed in New Zealand with an increase in the detection limit to <0.1 orgs/mL, as employed for the majority of samples analysed for *Legionella* bacteria in this study.

Factors associated with the presence of indicator bacteria

The relatively small number of rainwater tanks surveyed (N=35) and the variability of the tanks with respect to materials, roof catchment characteristics and cleaning regimes in this study hindered the detection of relationships between rainwater tank characteristics and operating protocols and microbial water quality. It is important to elucidate these relationships for two main reasons. The first is to assist in targeting epidemiological studies to high exposure scenarios. Accordingly, if an increase risk of illness is not observed in epidemiological studies for high exposure scenarios then it can be assumed not to be relevant for low exposure scenarios.

Secondly, the premise of a risk management approach for the provision of water for drinking and other purposes is the use of multiple barriers as a means to prevent and reduce contamination of water supplies. It is therefore important to obtain information about roof catchment and rainwater tank materials and maintenance, rainwater tank design and operational interventions that minimise microbial contamination of rainwater tank water.

One way in which this information may be obtained is to survey a large number of rainwater tanks so that statistically meaningful results may be derived. However even if a large number of tanks are surveyed, the serendipitous nature of microbial contamination of each catchment surface or of water in the rainwater tank means that microbiological monitoring may not coincide with contamination events. Furthermore, as was the case with this study, rainfall is not easily predicted giving rise to logistics problems associated with the timing of sample collection, particularly where the survey encompasses a number of geographical locations. Also a cross sectional survey, particularly when performed in isolation from other surveys, is necessarily expensive and may not yield the desired outcomes.

An alternative approach is to perform experimental studies using indicator microorganisms fit for purpose, where levels of contamination and rainfall can be manipulated to reflect worse case scenarios that might be realistically encountered. In addition, roof material, tank material, presence of debris (high organics) and UV and temperature conditions can be controlled and manipulated in an experimental setting.

2.5 Conclusions

2.5.1 Chemical analysis

- The high lead concentrations in some tanks need to be investigated to find the frequency and source. Lead concentrations over time are not consistent for a single tank and temporal effects need to be understood before the hazard can be identified. As the majority of cities had at least one tank with high lead concentrations, this may be common for Australian cities.

- High zinc levels in some tanks may lead to taste problems if drinking the water, with the tendency for zinc levels to be site related. The levels of zinc seen are not likely to cause health related problems if the water is drunk.

- Occasional high levels of plasticisers and herbicides need further investigation as to the incidence in a larger sample, and over a longer period of time. As the incidence of high levels was low the risk may be minor though not insignificant if a large number of tanks are installed in a city. PAHs may be present in levels above the 2004 ADWG for Benzo-(a)-pyrene but this study was not able to detect levels below 0.1µg/L at best. Further testing with improved analytical detection limits is necessary.

- The use of rainwater in electric hot water systems designed for hard water (e.g. Brisbane municipal supply has higher conductivity, see page 38) may lead to an overactive sacrificial anode and production of explosive hydrogen gas in the hot water tank. This obviously presents a physical hazard with inappropriate use of the rainwater. The pH of individual tanks is also quite variable and the acidity in some tanks combined with soft water is likely to cause corrosion in metal pipes over time. The variable pH must also be kept in mind when considering disinfection options such as chlorination, which is most effective at a pH between 3.5-5.

2.5.2 Microbiological analysis

The following conclusions may be drawn from the microbiological water quality data for the National survey:

- Results showed that rainwater tank supplies appear to provide water of relatively poor microbiological quality when compared with conventional Australian urban water supplies. Furthermore, the detection of *Campylobacter* spp and *Salmonella* spp in some rainwater tanks confirmed the plausibility of gastrointestinal infection arising when tank water is drunk, or domestic hot water, which has not been heated sufficiently, is consumed incidentally.

- Results from this study supplement existing data about the prevalence of bacterial enteric pathogens in Australian roof-collected rainwater tanks.

3 Other Projects

3.1 Introduction

In addition to the CRC National survey, results of some ancillary rainwater tank projects are presented in this chapter of the report. These studies supplement National survey data with recently collected water quality data for rainwater tanks. However, as each of the ancillary projects have a variety of objectives and rainwater tank profiles (e.g. drinking water top-up versus stand alone tanks) and parameters monitored are not consistent across all projects, direct comparison of results is not always possible. Nonetheless, each set of results contributes to the body of knowledge in relation to tank water quality. Selected data from each of these projects is discussed although does not necessarily include all available project data.

Table 3.1 summarises the ancillary projects discussed in this report and describes the period during which water quality monitoring and analysis was undertaken and the organisation(s) undertaking the study. Chemical and microbiological parameters monitored for each of the projects are detailed under individual project sections, together with an explanation of the specific objectives of individual studies.

Table 3.1 Rainwater projects discussed in this section

Project	**Conducted under auspices of:**	**Water quality monitoring period Data analysed**
30 tank study	Brisbane City Council	16/07/03-30/03/05
YVW/CERES	Yarra Valley Water	5/12/03-10/09/04
Mutitjulu	CRC WQT Centre for Appropriate Technology ATSIC	7/8/05-19/5/04
Healthy Home Qld	Dept Natural Resources, Mines and Water	Sept 03 – Feb 04

3.2 Brisbane City Council Study (29 tanks)

3.2.1 Introduction

Thirty tanks with mains water top-up were initially recruited into the program, but one participant dropped out of the program before completion, due to a change of ownership. Samples were monitored monthly for microbiological and physico-chemical analytes and quarterly for heavy metals.

3.2.2 Methods

Tank selection and recruitment

'Your City Your Say' (YCYS) is a reference group run by BCC allowing residents to comment on issues relevant to Brisbane. Its members are generally considered to be more engaged in and informed about community issues than average residents. In 2002, YCYS members were invited to participate in the Sustainable Living in Brisbane project as a reward for time and efforts in contributing to BCC surveys and forums. Over 700 responses were received to the initial invitation.

Seventy-three homes were selected based on the ability of applicants to maximise water and energy savings. A phone survey was conducted to gather additional information. Thirty homes were then selected based on demographics, geographic spread, housing type and access to mains gas. Site inspections of the selected applicants were conducted to ensure installation of HWSs and RWTs could be carried out without major structural modifications.

The homes were chosen to represent a variety of detached housing styles, (e.g. Queenslander, lowset brick etc.) and different household types (singles, couples and families) within a 10 km radius of the CBD. Apartments and townhouses were excluded due to expected difficulties with installation of the RWTs and HWSs and complications of dealing with bodies corporate.

Other criteria for selecting the 30 homes included:

- Must own and live in their home with no plans to move in the next two years
- Willingness to contribute 40% of the cost (all participants contributed roughly this amount)
- The age of their current HWS (preference was given to those with older systems)
- How many products were already in the home (preference was given to those with the least number of products already)
- Roof/downpipes must not have the following as they are unsuitable for internal use of rainwater:
    - Fibro/asbestos
    - Thatching
    - Chimney or flue from an internal fireplace
    - CCA treated timber or
    - Lead flashing and/or lead-based paints.

Before final selection, each of the short-listed applicants was visited at home to explain the project in detail and gauge their level of commitment to participate. Brisbane Water plumbers also conducted a site inspection to confirm suitability for a RWT and HWS.

Agreements with Participants

An informal written agreement was entered into between BCC and each participant to the effect that BCC would provide the major part of the costs for the products and installation. In return, the participant obligations were to:

- Pay an agreed contribution towards the cost of products and
- Agree to participate fully in the required monitoring and survey program for a two year period.

Participants were given a package cost appropriate for their house and asked to pay approximately 40%. Depending on the range of products, this amount was between $1,100 and $1,500. BCC contributed substantial resources towards the purchase of the products while assuming total financial responsibility for installation, maintenance and repair over the two year life of the project, to ensure limited financial burden on participants.

Package inclusions

Participants were given a package appropriate to their home that included the following:

- RWT (Stainless Steel, Aquaplate or Poly/3000 – 5000 litres)
- Associated fixtures including pump, first flush devices and external tap
- Greenhouse efficient HWS: Solar Storage (gas or electric boosted), Natural or LP Gas (storage or continuous) and Heat Pump
- AAA-rated shower
- Ceiling insulation
- Compost bins

- Energy efficient lighting (compact fluorescent light bulbs)
- Flow restrictors to bathroom basins and kitchen taps
- Dual flush toilet
- Shower timers (installed December 2004) and
- ‘Smart Meters’ (five households).

The range of products each household received was based on:

- Products already in the home
- Number of people living in the home
- Type/construction/size of home
- Land area
- Ease of installation and
- Installation cost.

All available types of HWSs were used, as shown in Table 3.2. A gas system was often installed where the house already had gas reticulation, while good solar access enabled solar installation.

Table 3.2 Number and Type of Hot Water System

Type of Hot Water System	Number of Households
Natural Gas Instantaneous	7*
LPG Storage	1
Electric Heat Pump	2
Solar – LPG boosted	1
Solar – electric boosted	18

Note: * There were initially eight instantaneous gas systems installed, but one of these households withdrew from the program as they sold their house.

Installation

On behalf of Water Resources, Brisbane Water undertook the purchase and installation of the RWTs and associated plumbing fixtures. Brisbane Water plumbers undertook site inspections to ascertain the best location, size and style of RWT for each house and arranged for any necessary concreting to provide the RWT base. Generally, the criterion used for RWT sizing was to install the maximum size RWT that access would allow. The preference was for 4,500 to 5,000 litre RWTs as they could be used as a dual water supply and stormwater detention (1,200 litres) device. Fourteen installations in the trial were based on this criterion.

A range of RWTs (3,000 to 5,000 litres) and materials (Aquaplate, Stainless Steel and Poly) were installed in an effort to gain a greater understanding as to how individual materials may perform over time. Details of the types and numbers are given below:

- Stainless Steel (7)
- Aquaplate (17) and
- Poly (6).

The RWTs were plumbed to the internal toilets and, except in the case of instantaneous gas, also to the HWSs. This required the connection of a small electric pump. To ensure that households did not run out of water when the RWT was empty, the RWTs were connected to the mains water supply via a ‘trickle feed’ system. When the water level in the RWT becomes low, mains water automatically trickles into the RWTs under reduced pressure. A Reduced Pressure Zone (RPZ) valve was fitted between the HWS and the mains cold water supply to prevent backflow of any rain water into the mains water system.

Suppliers nominated their own installers for all products, except the RWTs and associated plumbing. The manufacturers of the electric-boosted HWSs provided electricians (or suitably qualified plumbers). Houses were fitted with tempering valves to guard against scalding. Participants were given an information pack about their products, with guides on how to use and maintain them.

Regulatory Requirements

As the retrofit installations were significant, BCC plumbing inspectors visited all sites to ensure installations complied with statutory plumbing requirements. Independent safety inspections of all HWSs were carried out shortly post-installation by Gasworks and Plumbing Pty Ltd to check compliance with plumbing and electrical standards.

Legislation requiring the installation of tempering valves to every new HWS installation was enacted part way through the project installation phase. Properties not initially fitted with tempering valves were revisited and the valves installed to ensure compliance.

Tank characteristics

Rainwater Tanks (RWT's) had a capacity of 3000-5000L and were topped up with 1000L of water from the municipal supply when water levels were low. Tanks were made of either Aquaplate (57%), Polypropylene (20%) or Stainless Steel (23%) with 21 of the 30 tanks (70%) connected to the hot water system (HWS). Of the HWS's connected to the tanks, most were solar (19) with 1 gas and 1 heat pump included. The HWS's not connected to the tank were all gas (8) with the exception of one heat pump (see below). Sixteen houses (53%) had trees overhanging the roofline, another thirteen houses (43%) had trees within 5m of the roof and one house had no trees near the roof.

Table 3.3 Distribution of Hot Water System types and Rain Water Tank connections

type of HWS	HWS not connected to RWT	HWS connected to RWT
solar	0	19
gas	8	1
Heat pump	1	1
total no. of tanks	9	21

3.2.3 Results

Physico-chemical parameters

Temperature

Detailed temperature analysis is given later in this section, under "Outdoor taps: Temperature data" (p.59) as it is more applicable to the microbiological water quality.

pH

The pH of the tanks ranged from acidic (pH = 5.1) to alkaline (pH = 9.1) with a near neutral mean pH of 7.4 (see Table 3.4). The average pH of tank water was only slightly less basic than municipal water though the individual variation was far greater in tank water as shown by the minimum value of 5.1 and the skewed pH distribution in Figure 3.2. The mean pH of 7.4 for tank water is higher than the 6.7 mean from the National survey, though the high individual variability is consistent with the data from tanks without mains water top up.

Table 3.4 pH values of tank water and municipal supply

	parameter	pH
Tank water	Mean=	7.4
	Min=	5.1
	Max=	9.1
	1st quartile	6.9
	3rd quartile	7.9
Number of samples =	610	
Municipal supply	Mean=	7.9
	min=	6.9
	max=	9.1
	1st quartile	7.8
	3rd quartile	8.0
Number of samples =	607	

The pH was significantly, though only marginally, affected by location, roof material, and conductivity – but not tank material ($P \leq 0.02$). Calcium concentrations correlated well with pH with 84% of the pH variation explained by the calcium concentration as shown in Figure 3.3 below. This is likely to be due to $CaCO_3$ and the alkaline nature and buffering capacity of this compound. The likely sources of this are from municipal water supply (added at the treatment plant) or from crusted matter (soil/dust) collected in tanks. The addition of municipal water containing $CaCO_3$ would explain the higher pH of tanks in this study compared to the National survey. Concentrations of aluminium, zinc and to a lesser extent lead were slightly affected by pH. There was a slight interaction with pH and copper concentrations after rainwater had passed through a hot water system, though again the association was weak and there is a lack of sufficient comparative data from hot water systems connected to municipal water supply. The effects are shown in greater detail for each metal under the relevant headings in this section.

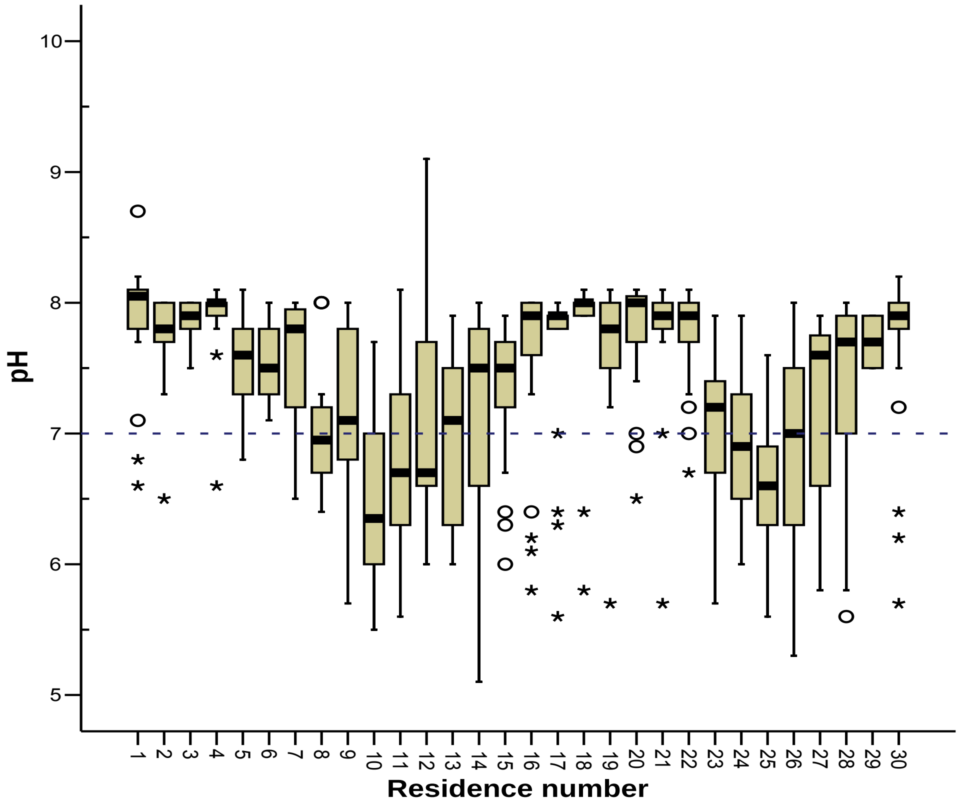


Figure 3.1 Boxplot of pH values for each tank location
Solid black bar shows median value, limit of shaded box is 25th and 75th percentile, range is shown by t-bars, "o" indicates outlier value, "*" indicates extreme value.

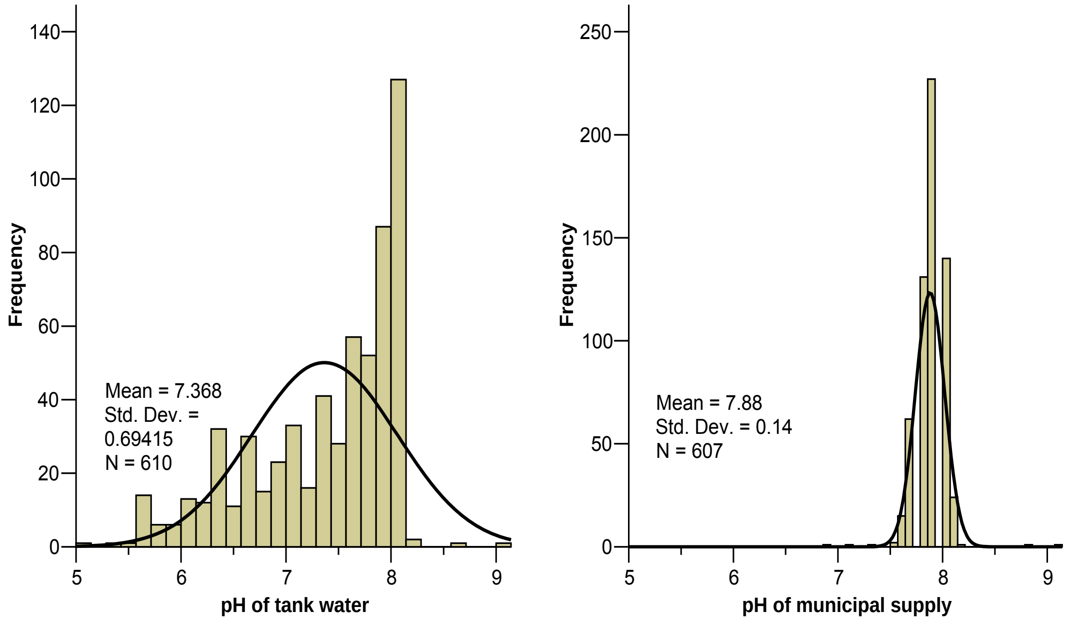


Figure 3.2 Comparison of pH distributions for tank water and mains water (normal curve drawn).
pH distribution of tank water is skewed to low pH values

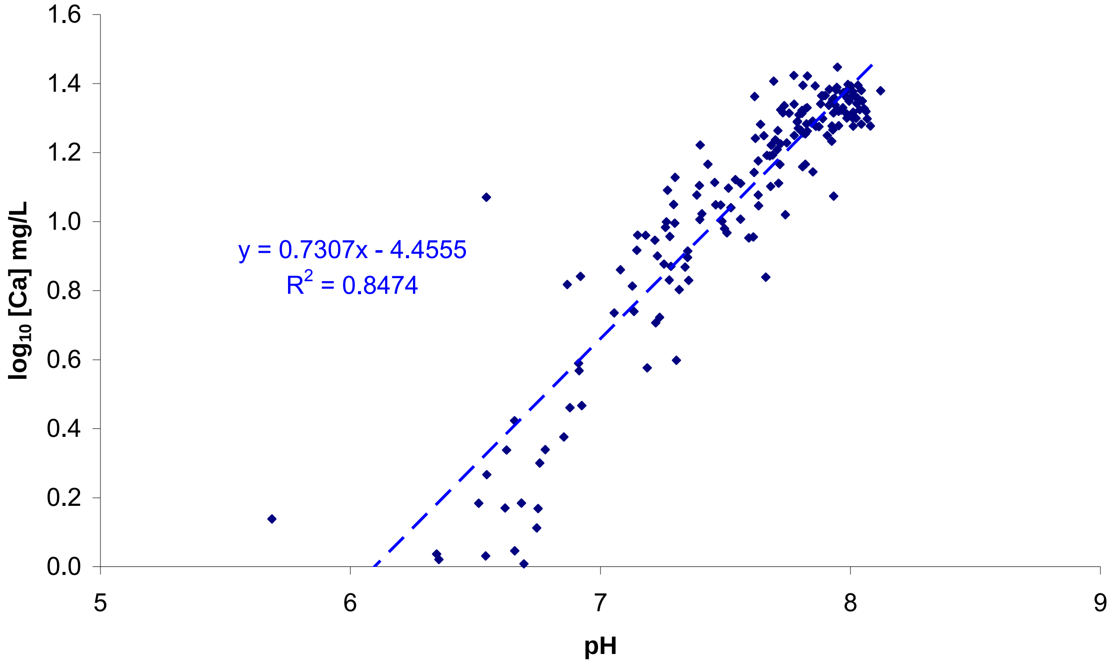


Figure 3.3 Correlation of Calcium concentration (mg/L, log base 10) and pH.

Conductivity and ionic composition

The conductivity of all samples from the 30 tanks averaged 229 µS/cm, which is approximately four times the average of tanks in the National survey without mains water top up, but half of the average value of Brisbane mains water (mean conductivity Brisbane municipal water = 409µS/cm). Correspondingly the mean calcium, magnesium, sodium and potassium concentrations are higher than those from the National survey but lower than those from Brisbane mains water supply in similar proportions to conductivity. Thus, the mains water top up in this situation appears to increase the hardness and ionic concentrations of the rainwater to approximately half that in the mains water itself. This may have benefit in limiting the corrosiveness of the water and permitting the safe use of rainwater in hot water systems. However, the degree of mixing between rainwater and mains water will be highly variable, being dependant on the meteorological conditions that prevail at the time. This method of reducing the corrosiveness is therefore unreliable.

Table 3.5 Conductivity and ionic composition of Brisbane tanks with mains top up

	Conductivity at 25oC (µS/cm)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
total tested	610	205	205	205	205
% Detected	100%	86%	77%	93%	68%
Mean	**229**	**14.8**	**9.1**	**21.3**	**2.8**
Min	6	1.0	1.2	1.1	1.0
Max	493	28.0	14.4	47.2	4.1
1st quartile	48	9.0	5.7	9.4	2.2
3rd quartile	395	21.0	12.5	32.9	3.4

Trace metals

Aluminium

Aluminium was detected in all samples and levels ranged from 5 to 122 µg/L, with a mean of 37µg/L for total aluminium (measured by ICP-MS). There was a significant ($P<0.01$) though weak relationship ($R^2=0.47$) with pH and aluminium, with decreasing aluminium concentrations when pH lowered from 8 toward 5 as shown in Figure 3.4 below. There was no effect of roof or tank type on aluminium concentrations ($P=0.16$ & 0.77 respectively) and no interactions. The decrease in Aluminium concentration toward pH 5 is expected given the normal solubility versus pH curve for aluminium. All samples for total aluminium were below the 2004 ADWG levels for soluble aluminium.

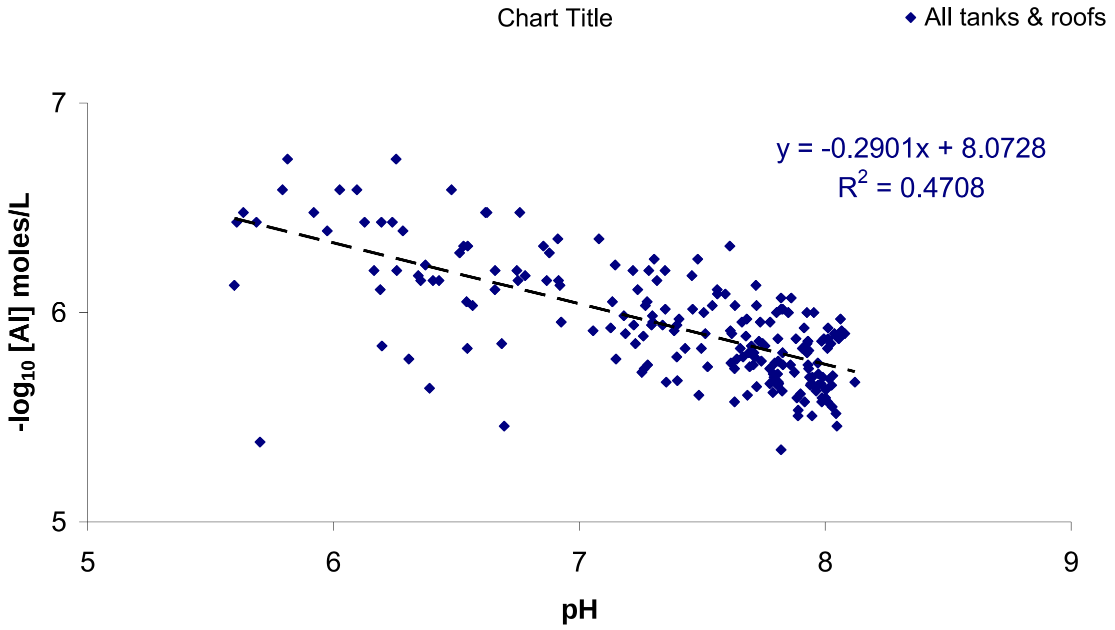


Figure 3.4-Log Aluminium (moles/L) Vs pH, Brisbane study
Note: as Al concentrations decrease the –Log increases on the y- axis.

Barium

Barium was detected in 86% of samples where concentrations averaged 19µg/L which was slightly less than the average mains water barium concentration of 27µg/L as measured at the kitchen tap. Even the maximum concentration of 42µg/L is well below the 2004 ADWG of 700µg/L and as such barium does not present any health risk from these tanks.

Cadmium

Cadmium was only detected in 11 samples (5%) that were tested for cadmium and 7 of these samples were from one tank, approximately 5km from the CBD and downwind of a glass factory. Of eleven samples where cadmium was detected, seven equalled the 2004 ADWG level of 2µg/L. Four of the seven high concentration samples were from the tank near the glass factory. The glass factory is the largest emitter of cadmium to the atmosphere in Brisbane (56kg during 2003-2004 to the atmosphere) with oil refineries, aeroplanes and power stations located near the Brisbane airport also large emitters (NPI, 2005). The other tanks where the cadmium was detected were approximately along a NE-SW line, southwest of the airport. The location downwind from the large emitters of cadmium is possibly the reason for detecting the cadmium in these tanks, though there were other tanks downwind in a similar direction in which cadmium was not detected. The other possibility is local sources specific to the site (e.g. leaching from PVC pipes, contaminant in zinc used for zincalume).

Chromium

Only 2% of samples detected chromium with the mean and maximum values of total chromium (0.005 and 0.011mg/L respectively) five times less than the 2004 ADWG value. The guideline value is set for the toxic form of hexavalent chromium (Cr^{VI}). Measurement of total chromium by ICP-MS does not give the oxidation state, though this is unnecessary given that the total concentration is less than the guideline for Cr^{VI}. The incidence of detection for chromium increased from 2% in tank water to 5% after the hot water system though the mean and maximum concentrations were marginally reduced.

Copper

All tank water samples had some copper present with a mean concentration of 0.06 mg/L and a maximum of 1.23 mg/L. The maximum concentrations exceeded the aesthetic but not the health 2004 ADWG value. There was a significant (P<0.01) though weak correlation (R^2=0.22) between copper concentration and pH in hot water taps connected to the rainwater tank as shown in Figure 3.5. Average copper concentration for hot water systems connected to mains water supply is lower than those connected to rainwater tanks (0.087mg/L, N=7 compared to 0.281mg/L, N=126). The average copper concentration did increase from 0.058mg/L in the tank to 0.281mg/L after passing through the hot water system which was a statistically significant increase as shown in Figure 3.6.

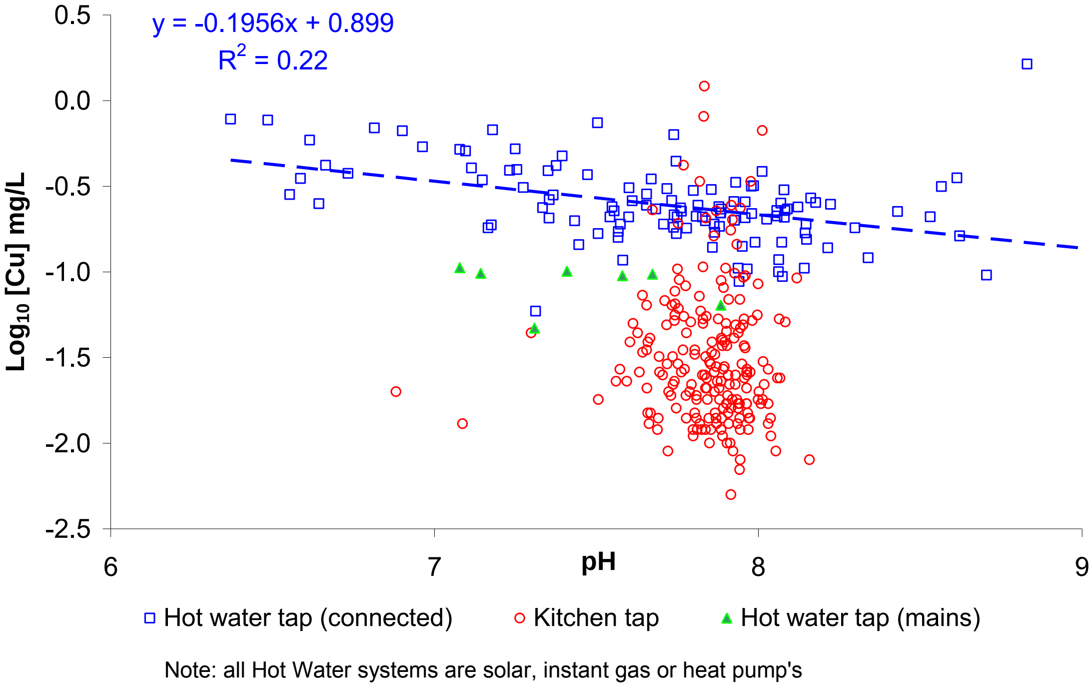


Figure 3.5Copper concentrations vs pH for hot water systems connected to rainwater tanks compared to mains water supply.
Regression significant (P<0.01, R^2=0.22)

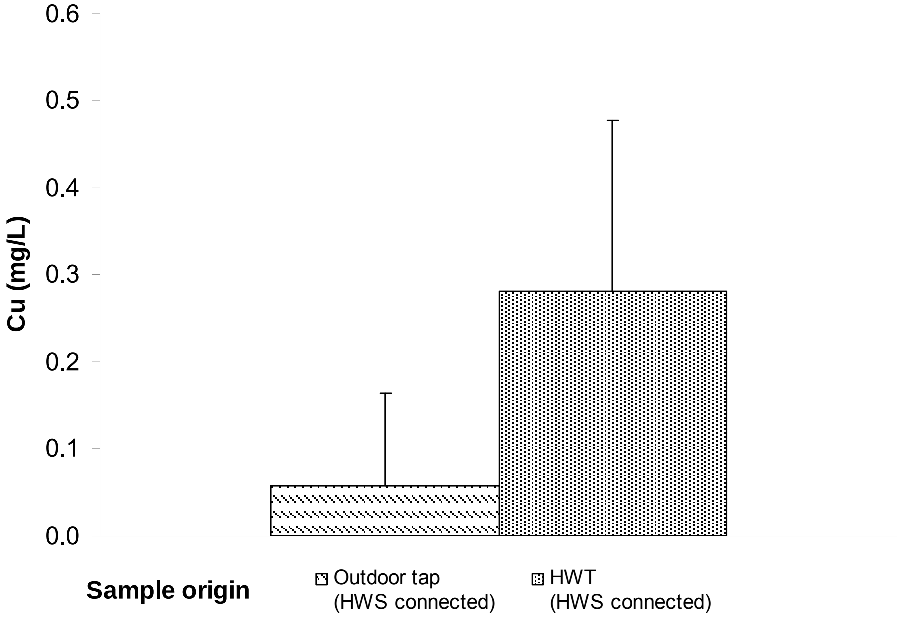


Figure 3.6 Copper concentrations before and after hot water systems - only tanks connected to the hot water system included.
Statistically significant T test (P<0.0.1). Mean ± standard deviation indicated.

Iron

Iron was detected in 95% of tank samples. The mean iron concentration in tank water matched that of the mains water supply which was 46µg/L. The maximum value of 2.8mg/L from mains water was 3 times the maximum of 0.96mg/L from tank water, though both of these values exceeded the 2004 ADWG aesthetic value of 0.3mg/L. As such the rainwater is of equal or better quality for iron concentrations than the municipal supply, though in isolated cases both may have iron levels that can be tasted by consumers. Iron concentrations decreased after passage through the hot water system. This is probably due to some oxidisation and precipitation of insoluble Fe^{2+}.

Manganese

The mean and maximum of concentration of manganese at 7µg/L and 47µg/L respectively were at least half of the 2004 ADWG aesthetic value of 100µg/L and lower than the mean value for municipal supply which was 10µg/L. Based on this data manganese does not present as a health risk if tank water is drunk.

Nickel

Only 1% of rainwater tank samples detected nickel with a mean and maximum concentration of 0.006mg/L and 0.011mg/L respectively which was similar to the values for the municipal supply. This mean concentration of nickel in tanks was approximately half of the 2004 ADWG Health level 0.02mg/L. However after the water passed through the hot water system the incidence of detection increased to 20% of samples and the mean and maximum concentrations increased to 0.011mg/L and 0.110mg/L. The maximum concentration of nickel is an order of magnitude higher than the recommended concentration and could be a concern if people drink water from the hot water tap. In this data 4 out of 133 hot water tap samples (3%) were above the guideline concentration, two from the same tank. All hot water tap samples with high nickel concentrations came from hot water systems connected to the rainwater tank.

Lead

Lead was detected in 19% of rain water tank samples and the concentration was found to be equal to or above the ADWG (2004) of 0.01mg/L in 7% (14 / 205) of samples tested. By comparison the municipal water had only one sample (0.5%) with a lead concentration ≥ 2004 ADWG and the incidence of lead detection was only 1%. The high lead concentrations in rainwater samples came from 10 separate locations (see Figure 3.7) with only 3 tanks having more than one sample with elevated lead levels. Eighteen of the 30 tanks tested did not detect any lead at all. Statistical analysis, using ANOVA, of lead concentration dependant on tank location found significant differences between locations, (F=1.6, P=0.03) though the assumption of equal variances was violated due to the majority of tanks with lead levels below the analytical detection limit. Tukeys post hoc analysis showed tank location 18 in Figure 3.7 was significantly different from tanks where no lead was detected. Location 18 was approximately 3km north-west of the city centre and had 3 samples with lead ≥ ADWG value (2004). There was no association found with lead levels and time of year, rainfall intensity or zinc levels.

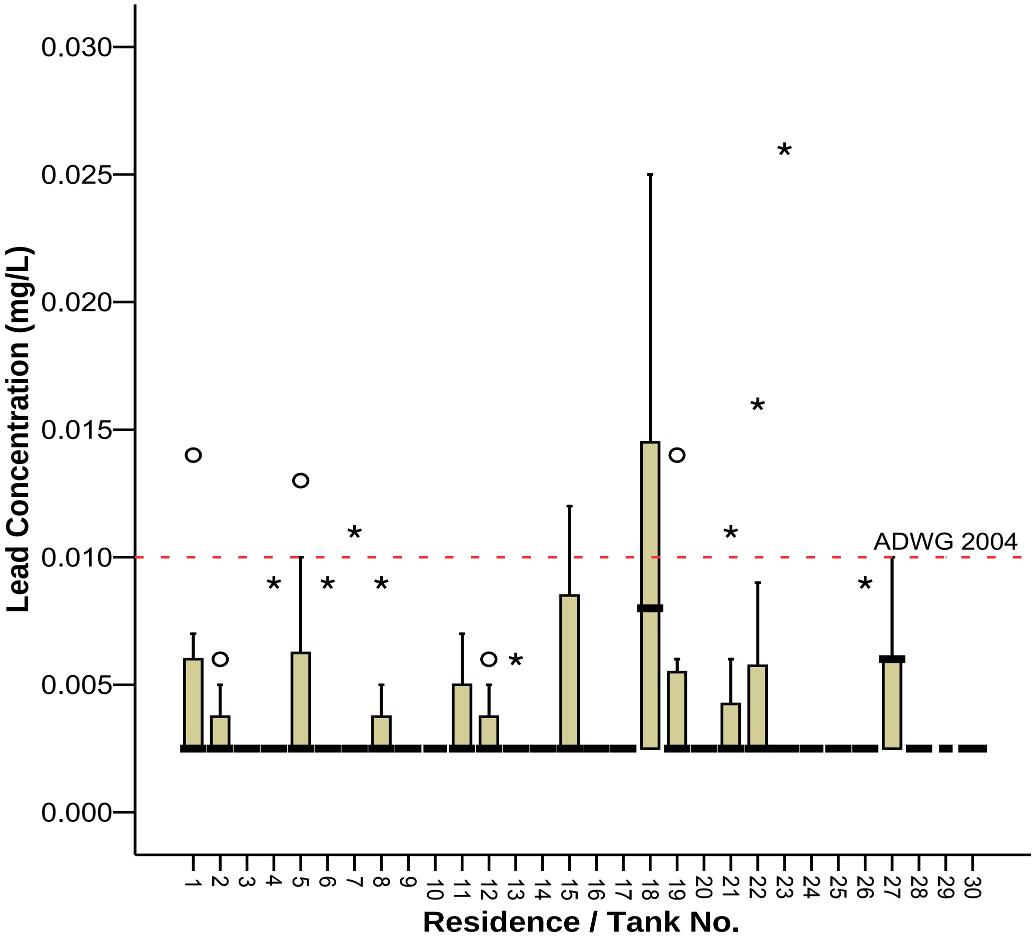


Figure 3.7 Boxplot (Median, 1st & 3rd quartiles, min, max, outliers and extreme values) of lead concentration grouped by tank.
(° indicates extreme values, * indicates outlier values, solid black line = median, range indicated by T-bar, not detected values recoded to 0.0025 which is ½ the detection limit of 0.005mg/L)

The pH of the tanks had a significant (P<0.01) though very minor effect (R^2 = 0.15, non detects removed) on lead concentration in tanks with no interaction of pH, roof type or tank type as indicated in Figure 3.8. The variation of lead concentration with pH is expected given normal solubility vs. pH curve for lead.

For hot water tap samples where the HWS was connected to the rain water tank there was no correlation of pH and lead concentration (non detects removed).

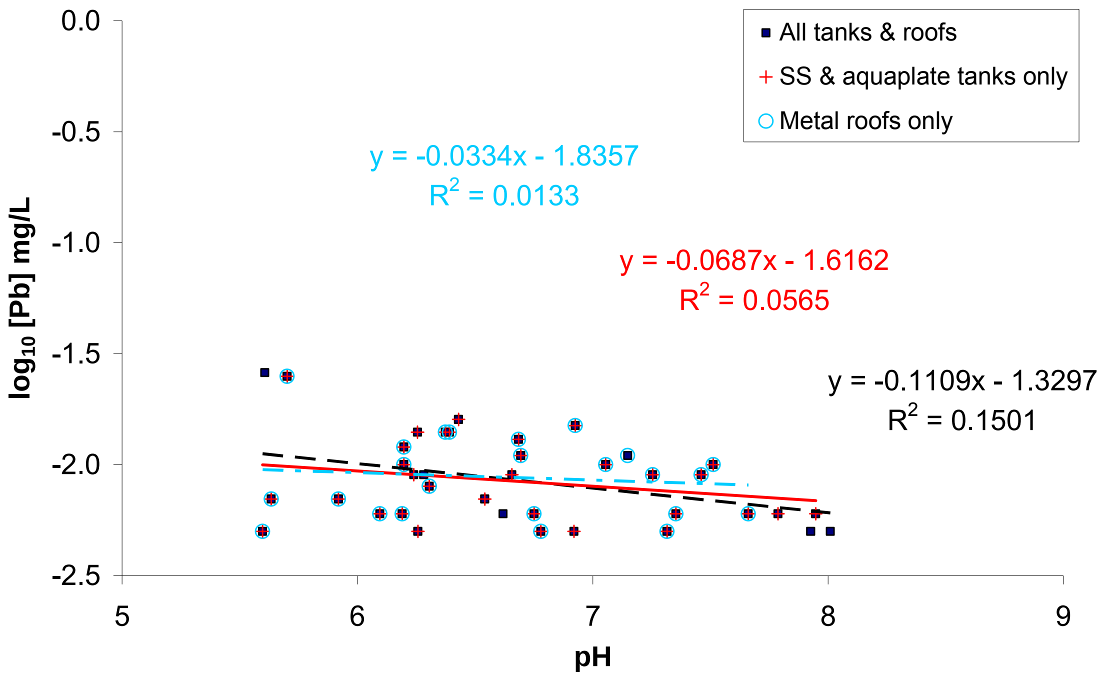


Figure 3.8 Lead concentration in rainwater tanks (mg/L) Vs pH

Similarly to nickel the incidence of lead detection increased from 19% to 41% after passing through the hot water system and the mean lead concentration increased from 0.009 (rainwater tank) to 0.011mg/L (post hot water system). The mean value was calculated excluding tanks where lead was not detected and the mean of the rainwater and the hot water were not statistically different when calculated in this way. The mean lead concentration for hot water systems connected to the rainwater tank is just above the 0.01mg/L 2004 ADWG value. Of all hot water samples tested 15% (20/133) were above the guideline value. Only one location had data from a hot water tap that was not connected to the rainwater tank and there was no difference in lead concentrations between the mains water and hot water tap at this residence.

The effect on lead concentrations of rainwater passing through hot water systems is shown in Figure 3.9 below where it is clear that the concentration of lead is increased in many samples, above that found in the same water before the hot water system. As indicated in this diagram 16% of hot water samples (only hot water systems connected to the rainwater tank included) had lead concentrations ≥ the 2004 ADWG, compared to only 4% of samples ≥ the 2004 ADWG prior to the hot water system.

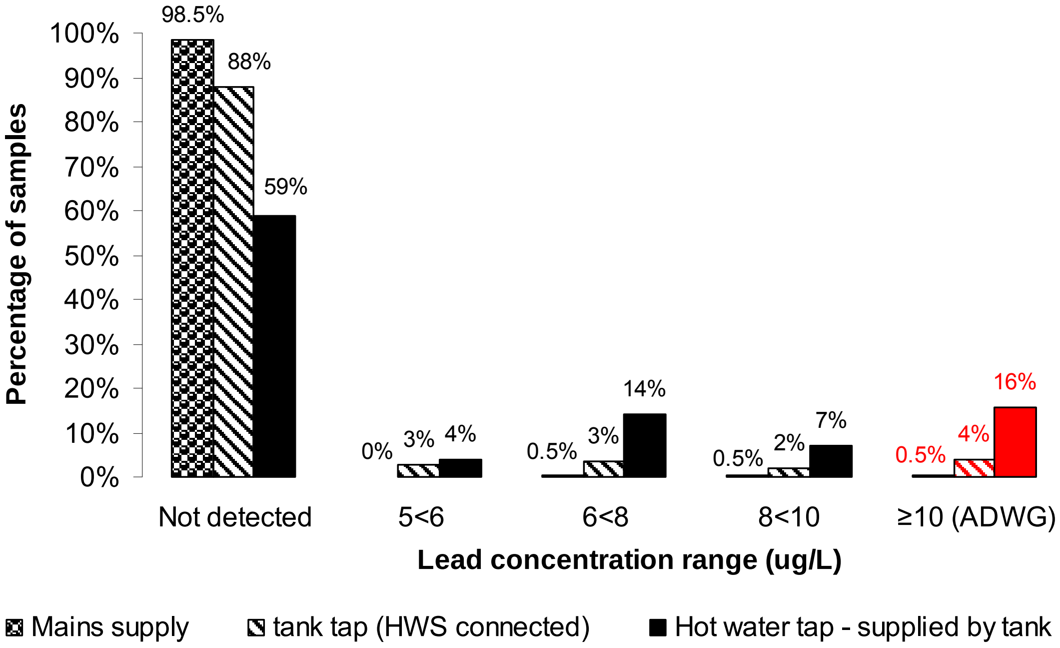


Figure 3.9 Comparison of lead concentration distributions between mains, tank and hot water. ADWG for lead is 10ug/L.

This suggests that passage of municipal water through the hot water system does not increase lead whereas rainwater used in hot water systems does, however further data is needed from mains water before and after the hot water system to confirm the hypothesis. The reason for increased incidence of lead in hot water tap samples where the HWS is connected to the rainwater tank may be related to the increased corrosiveness of the tank water leaching lead out of the hot water system and joints.

Zinc

Zinc was detected in all rainwater tank samples with a mean value of 0.21mg/L. Zinc did not exceed the 2004 ADWG aesthetic value of 3mg/L in any samples including the hot water tap and kitchen tap (municipal supply) samples.

Zinc concentration in the tank was significantly (P>0.001) though weakly correlated to the pH (R^2=0.32) (Figure 3.10).

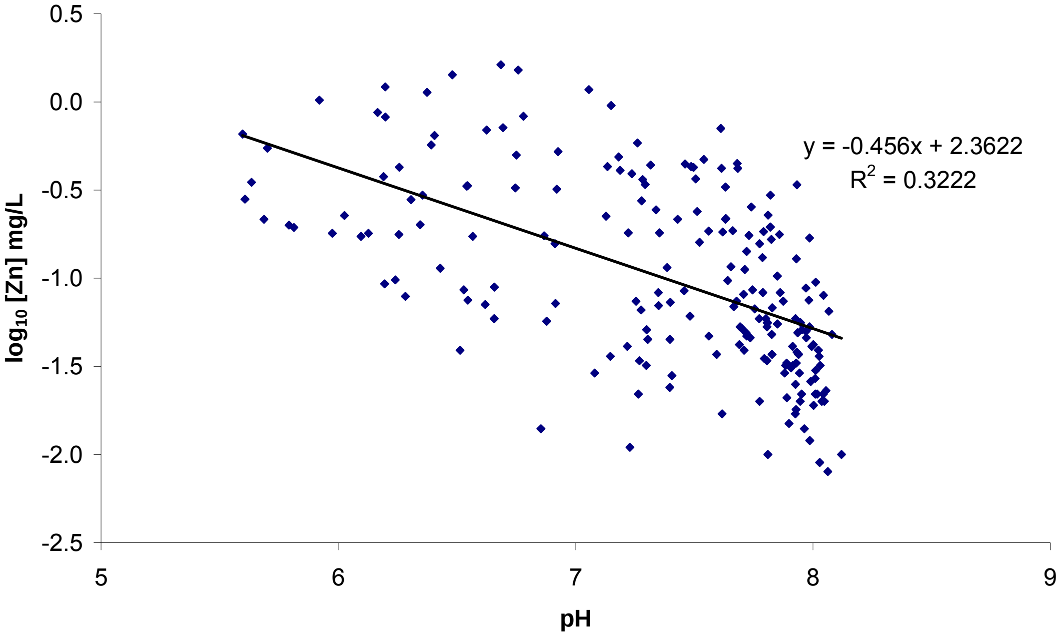


Figure 3.10 Log10 of Zinc concentration (mg/L) Vs pH for Brisbane 30 tank study

Table 3.6 Summary of values for metals tested in outdoor tap samples (tanks) -Brisbane 30 tank study

Metal	Aluminium	Barium	Cadmium	Chromium	Copper	Iron	Manganese	Nickel	Lead	Zinc
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
No. samples	205	205	205	205	205	205	205	205	205	205
% Detected	100%	86%	5%	2%	100%	95%	100%	1%	19%	100%
Mean	0.037	0.019	0.0021[1]	0.005	0.059	0.046	0.007	0.006	0.009	0.21
Min (detection limit)	0.005	0.005	0.001	0.002	0.009	0.005	0.001	0.004	0.005	0.01
Max	0.122	0.042	0.002[1]	0.011	1.225[2]	0.961[2]	0.047	0.011	0.026[1]	1.63
1st quartile	0.021	0.011	0.001	0.003	0.027	0.010	0.004	0.004	0.006	0.04
3rd quartile	0.050	0.027	0.002[1]	0.005	0.064	0.035	0.008	0.008	0.011[1]	0.24

[1] equal or exceeding the ADWG 2004 health value,

[2] equal or exceed the aesthetic ADWG 2004 values.

Incidence of detection in rainwater tanks, municipal supply and hot water

Comparison of rainwater, hot water and kitchen tap samples shows that the incidence of detection is higher in rainwater tank samples compared to municipal supply for cadmium, chromium, iron, lead and zinc. Compared to rainwater, when sampling the hot water tap nickel and lead have a large increase in incidence of detection and chromium a minor increase. All but one of the hot water systems sampled is supplied by the rainwater tank, so the increase can be directly compared to the incidence of detection in rainwater. Thus, after rain water passes through the hot water system it is more likely to contain higher concentrations of chromium, lead and nickel than before. This is represented in Figure 3.11 below.

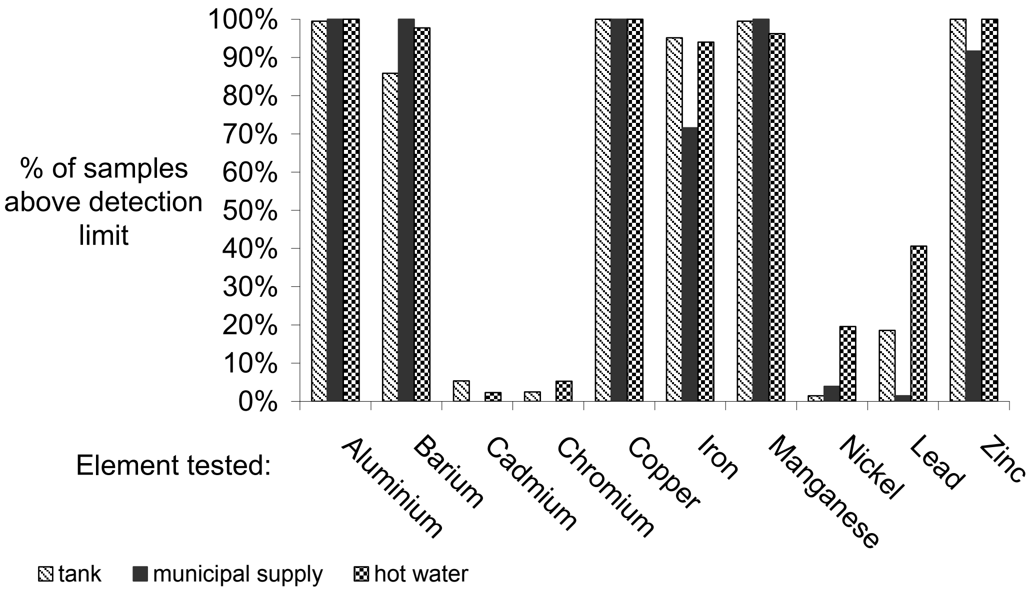


Figure 3.11 Percentage of samples where metals were above the detection limit.

A summary of the data for selected metals in rain water, hot water and kitchen tap samples (municipal supply) is shown in Figure 3.12 below with the 2004 ADWG indicated for each metal. As shown, the maximum concentrations for nickel and lead in rain water and hot water samples exceed the guideline values while the maximum cadmium concentrations from rain water and hot water equal the guideline values. Mean and maximum lead concentration in mains water exceeds the 2004 ADWG in Figure 3.12 though these values are based on 3 samples only, which is reflected in the low incidence of detection shown in Figure 3.11. Nickel is the other element affected by low numbers of samples where it was detected and mean values for tank water and mains water must be interpreted with this in mind. As mentioned previously the incidence of detection for nickel and lead increased after passing through the hot water system (Figure 3.11).

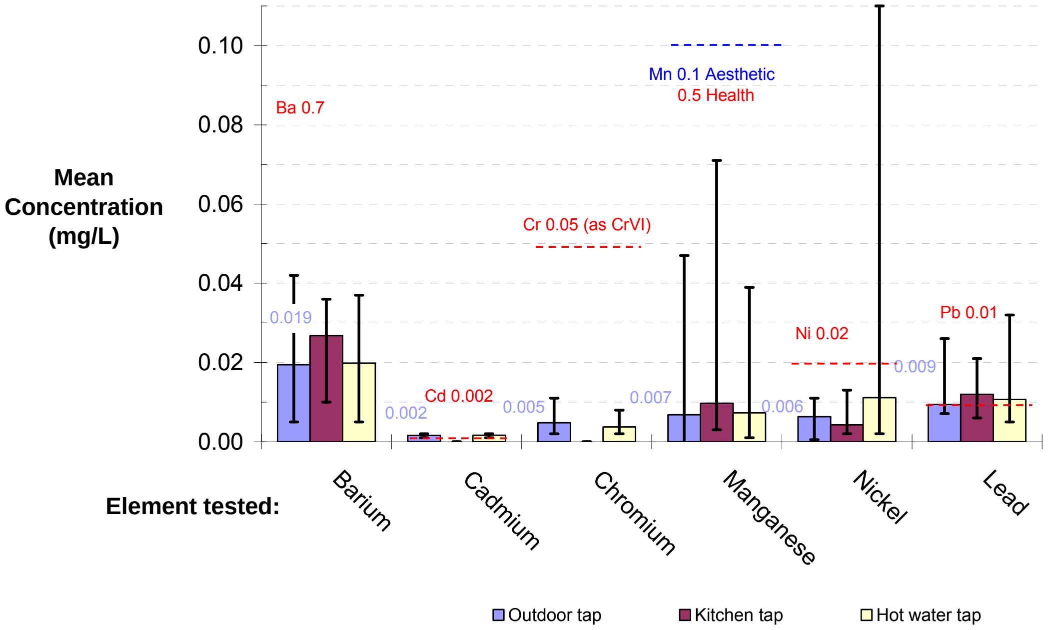


Figure 3.12 Summary of mean concentration and range compared to 2004 ADWG values for selected metals.

Max. and Min. indicated by error bars, mean value for each metal indicated in purple above the appropriate element, kitchen tap samples did not detect Cd or Cr, 2004 ADWG health values shown as red dashed line and value indicated in red above element, 2004 ADWG aesthetic value shown as blue dashed line and value above element. Mean values calculated after non-detects removed and should be read in conjunction with Figure 3.11.

Microbiological data

Presentation and discussion of Brisbane City Council rainwater tank microbiological results is divided into three parts. Firstly, results for the outdoor tap (representative of untreated tank water) are presented and discussed. These outdoor tap samples are supplied with a mixture of water originating from the roof catchment and mains water, with the proportion of each water type depending upon the amount of rain and water usage rates prior to the monitoring event. Secondly, microbiological results for the hot water tap are presented. The impact of elevated temperature on the prevalence of micro-organisms in supplied hot water was analysed. Finally, results for the kitchen cold water tap are discussed. These results represent the quality of the reticulated drinking water supply used to ‘top–up’ rainwater tanks.

Outdoor taps: Microbiological results

Bacteriological results for the outdoor taps show the prevalence of *E. coli* to be 22% and that of total coliforms to be 43%. Plate (also referred to as heterotrophic plate count) count bacteria (37^{o}C/ 48hrs) were detected in all outdoor tap samples. These results are in accord with expected results as outdoor taps are supplied by roof collected rainwater, which is susceptible to faecal contamination from small birds and animals.

Table 3.7 Summary microbiological data for outdoor taps

Parameter	% Prevalence	N	Median	Range
E. coli /100mL	22%	579	6	1-600
Faecal coliforms/100mL	25%	581	8	1-600
Total coliforms/100mL	43%	580	30	1-800
Plate count (35^{o}C/48hr)	100%	579	8100	1-60,000

E. coli bacteria are present in the gut of warm-blooded birds and animals and their presence indicates recent faecal pollution. In contrast, coliform bacteria are found in both faeces and the environment. Hence, the greater prevalence of total coliforms, as compared with *E. coli* in tank water, may be associated with a non faecal source of contamination (e.g. vegetation and soil), the greater persistence in tank water of total coliform bacteria derived from a faecal source, as compared with *E.* coli, and/or the proliferation of total coliform bacteria in tank water associated with high nutrient levels. Plate count bacteria numbers are inclusive of both faecally derived bacteria and other bacteria from environmental sources capable of growth at 35^{o}C/48hrs. Results show that while numbers of plate count bacteria are some 2 orders of magnitude higher than total coliform counts and 2-3 orders of magnitude higher than *E. coli* and faecal coliform counts, all bacteria show the same seasonal trend with an increase in count associated with increasing rainfall. Results are represented diagrammatically in Figure 3.13.

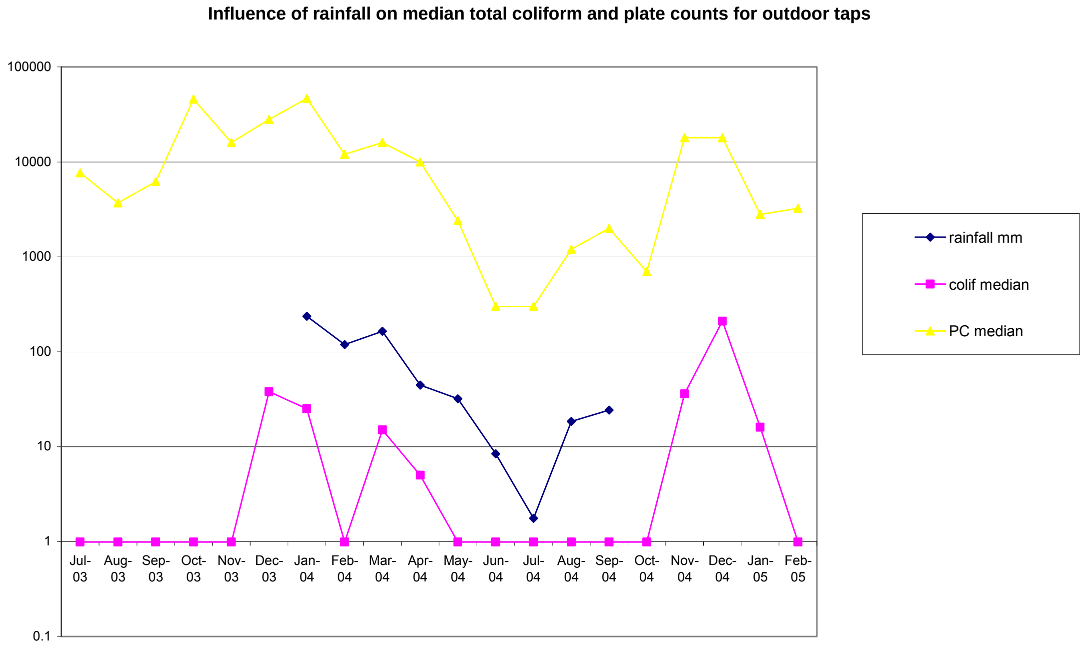


Figure 3.13 Influence of rainfall on median total coliform and total plate counts for outdoor taps (change to black – yellow line not very visible)

These results are not surprising given that material on the roof catchment comprises both faecal matter (from birds and small animals) and leaf litter, debris, soil etc. An increase in the levels of both faecal and environmental bacteria may occur in tank water following rain. Input of rainwater, depending upon the intensity of rainfall, may also result in a disruption of the sediment layer (if present) in the tank and the re-suspension of bacteria from the sediment into the liquid phase, thereby resulting in an increase in bacterial counts in the water.

It is also probable that the seasonal trend observed is enhanced as a consequence of the top-up provision of the rainwater tanks. During periods of low rainfall, the tanks are topped up with high quality drinking water. Improvement in bacterial quality of tank water during low rainfall periods thus may occur as a consequence of a combination of factors. These include the infrequent and minimal input (or absence) of rain water bearing faeces from the roof, the dilution of the numbers of bacteria in the tank as a consequence of the input of water of high bacteriological quality and/or bacterial die-off due to residual chlorine in the in-coming reticulated water.

One potential hypothesis for the presence of high numbers of faecal and other bacteria in some rainwater tanks but not others, assuming a similar proportion of top-up reticulated water in all tanks, is the presence of trees overhanging the roof catchment. Such trees may provide a roost for birds, nesting sites for small animals, a means for animals to access the roof catchment and additional vegetative matter supplying nutrients on which bacteria are able to grow. A comparison of bacterial results for rainwater tanks with trees overhanging the roof catchment and those with trees within 5m is given in Table 3.8.

Table 3.8 Comparison of bacteriological results for trees overhanging roof catchment versus 5m proximity

Parameter	**Trees overhanging roof**			**Trees within 5m proximity**		
	Median	Range	% prevalence	Median	Range	% prevalence
E. coli/100mL	6	1-260	23%	7	1-600	21%
Faecal coliforms/100mL	9	1-260	27%	8	1-600	24%
Total coliforms/100mL	30	1-800	46%	40	1-800	41%
Plate count (35°C/48hr)	14,000	1- 60,000	100%	2700	2-60,000	100%

These results show similar levels of indicator bacteria in tank water irrespective of whether or not trees overhang the roof catchment supplying the rainwater tank. However, median numbers of plate count bacteria are an order of magnitude higher for tanks where trees overhang the roof catchment. Segmented results show the same seasonal pattern as for all tanks combined. These results indicate that the seasonality in bacterial counts is associated primarily with rainfall (i.e. run-off and associated top-up of tanks) and not with proximity of trees to the rainwater tank roof catchment.

The ability to extrapolate microbiological data obtained for rainwater tank water in the Brisbane City Council study to other rainwater tanks is somewhat limited. Whilst each rainwater tank was monitored on a number of occasions, giving longitudinal data showing temporal variations in microbiological water quality for individual tanks, interpretation of results is confounded as tanks were topped up with water from the conventional tap supply. Thus, results are strictly only relevant to rainwater tanks topped up with water of the same quality as the conventional Brisbane tap supply. In addition, results are only relevant to tanks with a similar set point at which top-up occurs as this set point determines the factor by which existing water in the rainwater tank is diluted. Nonetheless, this data is valuable as the Brisbane City Council rainwater tank configuration is being contemplated elsewhere. Results indicate that where a water supply of good microbiological quality (and one where residual chlorine is present) is used to top up rainwater tank water, an improvement in the microbiological quality of tank water, as measured using indicator bacteria, is likely to occur.

Outdoor taps: Temperature data

Water temperature at each of the 29 outdoor taps (representing tank temperature) was measured on most occasions when samples were collected for microbiological and chemical analysis. The mean water temperature for the whole monitoring period was 24.5°C and ranged from 12-52°C in individual tanks (see Table 3.9).

Table 3.9 Outdoor tap temperature in Brisbane 2003-2005

Parameter	*Units °C*
Mean=	24.5
min=	12
max=	52
1st quartile	22
3rd quartile	28
total tested=	581

The average temperature of the tanks followed a seasonal pattern as shown in Figure 3.14 below. Survey results show that during the summer months (December, January, February, March) in Brisbane mean tank water temperatures are 25°C and above. In addition, for all months except the winter months (June, July, August) mean water temperatures are in excess of 20°C.

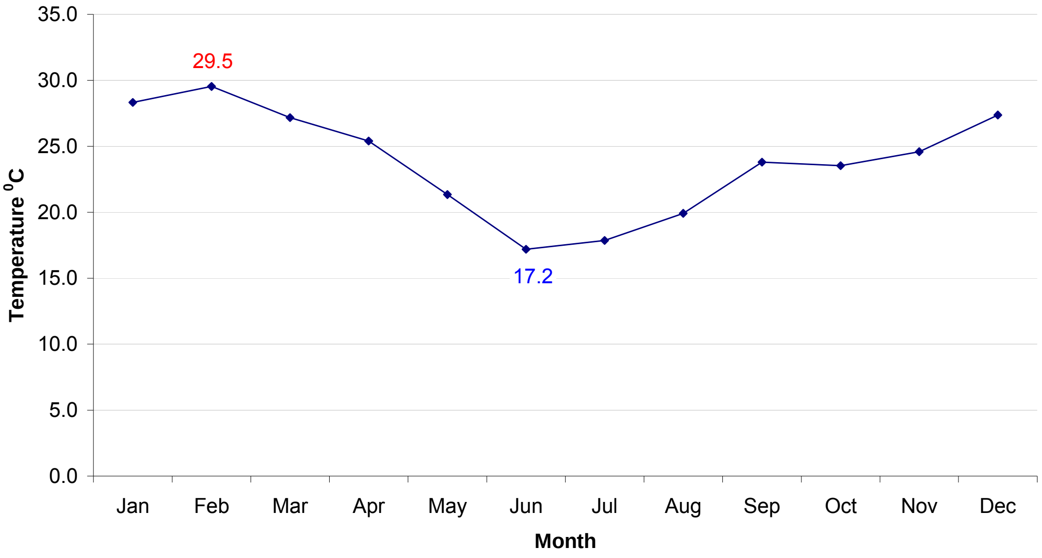


Figure 3.14 Mean monthly water temperature of tank water in Brisbane

More detailed analysis of temperature data, taking into account the time of day that temperature readings were taken, shows that mean tank water temperatures for the whole year remain relatively stable between the time periods over which samples were collected (0745-1435hrs) with lowest mean temperatures for the period before 0950hr. Figure 3.15 shows the mean temperature of water from all outdoor taps (aggregated) for the whole monitoring period and for June (Winter) and February (Summer) against the time of day that samples were taken. Results show that In Brisbane during June, mean water temperatures during the period 0950-1435hrs are generally 15-20°C and in February they are generally 25-35°C.

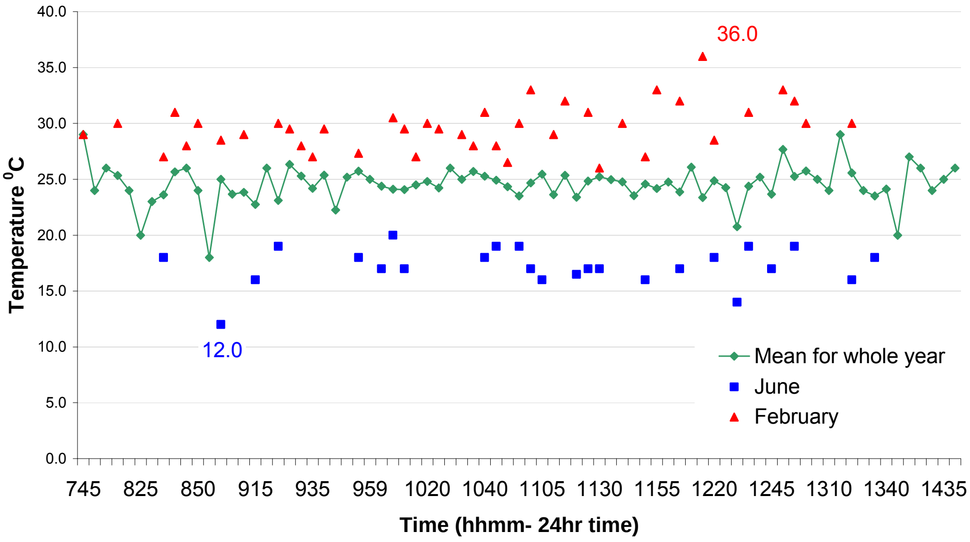


Figure 3.15 Mean temperature of rainwater tank water samples versus time of day samples collected

Scientific literature states that significant concentrations of legionellae will develop only in situations where temperatures rise above 20°C for prolonged periods. Thus, recommended control measures for legionellae in potable water systems include the provision that the cold water be kept cool, with temperatures at outlets not exceeding 20°C (WHO, 2002).

Mean recorded summer water temperatures for outdoor tap water, representing the water temperature of tank water in Brisbane are above the recommended 20°C for all months except the winter months. Of note however is that a comparison of mean water temperatures of reticulated water (indoor kitchen tap) also shows mean monthly water temperatures to be above 20°C during all months except the winter period (refer Figure 3.16).

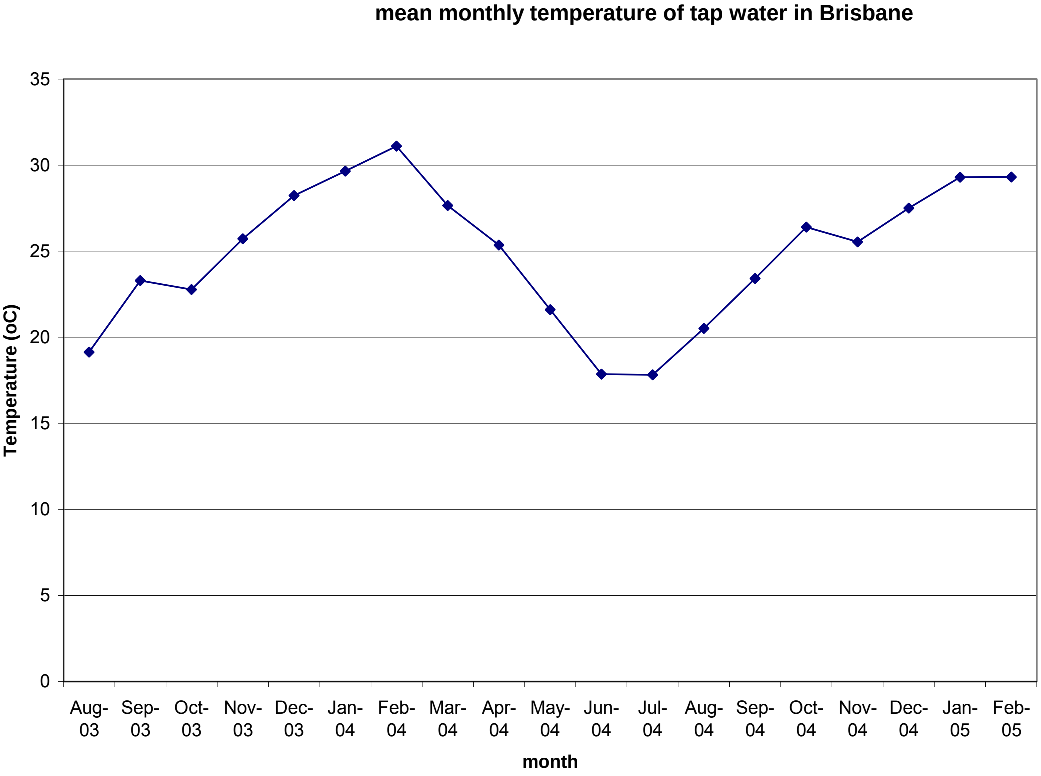


Figure 3.16 Mean monthly temperature of mains water in Brisbane as measured at the kitchen tap

Hot water taps

Microbiological results for hot water are given in Table 3.10. These results show low prevalence rates for *E. coli*, faecal coliform and total coliforms. Such results are in accord with the expected results as these indicator bacteria are easily inactivated by heat. For example, for *E. coli*, the observed D value at 55°C is 0.17 minutes (Merino et al 1995). Thus, operation of a hot water unit continuously at 60°C is expected to result in the absence of indicator bacteria on each monitoring occasion. The fact that these bacteria have been detected on some occasions is presumably attributed to fluctuations in hot water temperature. Temperature monitoring data (refer Table 3.11) shows that whilst a mean temperature of 51.9°C was recorded, hot water temperature was as low as 32°C on some occasions. On each occasion, *E. coli* / faecal coliforms/ total coliforms were detected, recorded hot water temperatures were 48°C and below.

Whilst heating to hot water temperatures is expected to result in a reduction in the number of bacteria, the presence of plate count bacteria in a large number of hot water samples is nevertheless to be expected as some bacteria are able to withstand temperatures in excess of 60°C. Results show that heating to hot water temperatures has resulted in a reduction in the median number of plate count bacteria, as compared with median counts for the outdoor tap, of some 2 logs and in 23% of cases has resulted in their removal.

Table 3.10 Microbiological quality of hot water

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	1%	382	3	2-4
Faecal coliforms/100mL	2%	382	3	1-11
Total coliforms/100mL	4%	382	2	1-49
Plate count (35°C/48hr)	77%	377	30	1-26,000

Table 3.11 Hot water temperatures

Summary statistic	Temperature °C
Mean	51.9
Min	32
Max	71
1st quartile	48
3rd quartile	55

Kitchen taps (reticulated drinking water)

Results for the cold water kitchen tap are presented in Table 3.12. These results show kitchen tap prevalence rates for *E. coli*, faecal coliforms and *E. coli* to be in accord with an Australian drinking water supply in compliance with Australian Drinking Water Guidelines (ADWG) and regulatory requirements. These results show the drinking water supply used to top-up the rainwater tank supply to be of high bacteriological quality. The 100% prevalence rate of plate count bacteria is also expected as water treatment protocols are not expected to result in the removal of all bacteria. The median plate count result of 12 orgs/ mL is in accord with a well treated drinking water supplies with excursion to 6000 orgs/mL (the maximum levels recorded) presumably associated with a build up of sediment / low water turnover etc at a particular tap.

Table 3.12 Microbiological quality of cold water at kitchen tap

Parameter	% Prevalence	N	Median	Range
E. coli/100mL	0%	577	Na	Na
Faecal coliforms/100mL	0%	576	Na	Na
Total coliforms/100mL	1%	576	4	1-17
Plate count (35°C/48hr)	78%	575	12	1-6,000

Key: NA = not applicable

3.2.4 Conclusions

The following conclusions may be drawn from the water quality monitoring data for Brisbane City Council rainwater tank study:

- Faecal coliform/ *E. coli*, total coliform and plate count bacterial levels follow rainfall (and proportion of mains water top-up) patterns with lowest median counts recorded in the period of lowest rainfall (June –August).
- Microbiological results indicate that seasonality in bacterial indicator levels is not determined by the proximity of trees (overhanging versus 5m distance from roof) to the rainwater tank roof catchment.

- Results show that the prevalence rate of *E. coli*, faecal coliforms and total coliforms in hot water is low in accord with the thermal inactivation of indicator bacteria at hot water temperatures of 60°C and above.

- Those occasions where indicator bacteria were detected in the hot water were associated in all instances with hot water temperatures of 48°C or below.

- Results show the drinking water supply used to top-up rainwater tanks to be of high microbiological quality and in compliance with drinking water regulations.

- Low indicator and total plate counts during periods of lowest rainfall are consistent with the infrequent and minimal input (or absence) of rainwater containing faecal washings from the roof catchment into the tank and the dilution / inactivation of bacteria in the tank occurring as a consequence of top-up of tank water with water of high bacteriological quality and /or bacterial die-off occurring due to residual chlorine present in the in-coming reticulated water.

- The ability to extrapolate microbiological data obtained for rainwater tank water in the Brisbane City Council study to other rainwater tanks is somewhat limited. Nonetheless, this data is valuable as the Brisbane City Council rainwater tank configuration is being contemplated elsewhere. Results indicate that where a water supply of good microbiological quality (and one where residual chlorine is present) is used to top-up rainwater tank water, an improvement of the microbiological quality of rainwater tank water, as measured using indicator bacteria, is likely to ensue.

- Rainwater has low levels of dissolved salts and is classified as soft water.

- It has a larger variability in pH than municipal supply.

- The added calcium carbonate from the municipal supply is a major determinant of the pH in tank water.

- Addition of municipal water with high TDS also increases the hardness.

- Due to the soft and sometimes acidic nature of rainwater, when used in hot water systems it leads to increases in the chromium, copper, lead and nickel in the hot water.

3.3 CERES, Melbourne, Victoria

3.3.1 Introduction

Victorian Government's Urban Development Authority *VicUrban* is undertaking a 8500 lot residential development north of Melbourne at Epping North, named Aurora. Sustainable urban design is a key feature of this development. This will be achieved by using AAA rated household appliances (low water use), rainwater tanks (optional), and recycling treated wastewater to residential properties via a third pipe system for toilet flushing and garden use. Yarra Valley Water Limited (YVW), the water authority responsible for provision of water and sewage services in the region will also be responsible for the provision of recycled water to this development from early 2008.

The rainwater harvesting system of the Aurora urban development is envisaged to comprise: a first flush by-pass, a 2.25KL storage tank, a pump and a solar hot water system (gas boost), operating at a minimum temperature of 60^{o}C to provide adequate disinfection. A potable water back up will be connected to the rain water supply system via an automatic supply selector. The supply selector determines whether rain water or potable water to be used depending on the water level in the rain water tank. A backflow prevention device will be connected to the supply selector to protect the drinking water supply from potential cross contamination. Cold potable water will be supplied at mains pressure and mixed with hot rainwater through a tempering valve to reduce hot water temperature to 45-55^{o}C (Nadebaum et al. 2004).

As this development introduces a number of new concepts and operational requirements that are different from those involved in servicing a conventional residential development, YVW and VicUrban commenced a pilot scheme at the Centre for Education and Research in Environmental Strategies (CERES) site in Brunswick, Victoria. The site at CERES was selected as it provides an indication of the likely future Aurora environment in 10 to 15 years time. The site provides a worst case environment as overhanging branches from trees allows contamination from leaf debris and provides animal access and perching places for birds (VicUrban 2005).

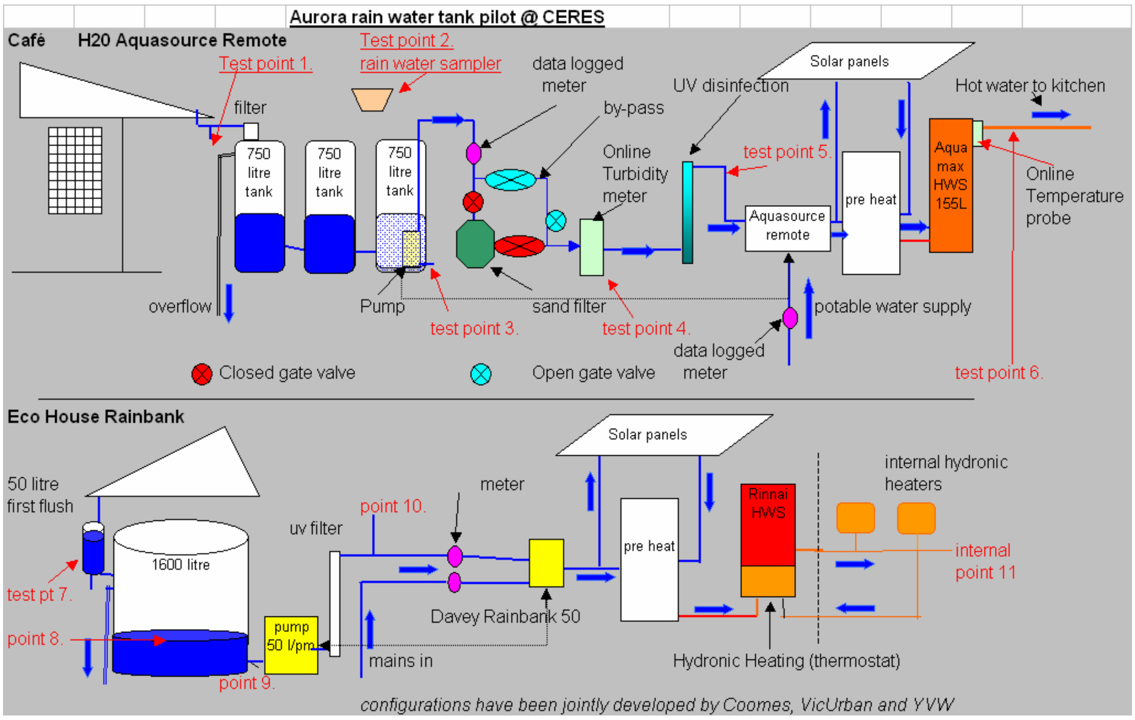
The rainwater harvesting configurations at CERES were jointly developed by Coomes Engineering, VicUrban and YVW as a result of a review of published rainwater quality studies, discussions with the Aurora advisory panel and YVW (VicUrban 2005). The rainwater quality trial for the harvesting of rainwater for hot water use at CERES was established to understand the risks associated with using rainwater for production of hot water with and without an additional barrier of Ultra Violet (UV) disinfection.

The CERES pilot scheme comprises water quality monitoring of two facilities at the Café and the Ecohouse. Water quality monitoring results for the period December 2003 – September 2004 are presented in this report.

3.3.2 Methods

Sample locations

A schematic of the rainwater harvesting systems at CERES and sampling locations at is presented in Figure 3.17.



configurations have been jointly developed by Coomes, VicUrban and YVW

Figure 3.17 Aurora Rainwater Tank Project at CERES, system configuration and monitoring points

Initial proposed monitoring frequency and parameters

A water quality monitoring program developed at the commencement of the study. A number of modifications were made to the original monitoring program as a consequence of the following:

- Parameters changes were made to come in line with those parameters being monitored in the CRC for Water Quality and Treatment National survey and comments received at various stages from participant parties.
- The frequency of planned monitoring was reduced for some parameters once the program began based on 'non- detections' of some water constituents on initial monitoring occasions.
- Additional temperature monitoring was undertaken at the solar preheat hot water tank at the Café as a consequence of recommendations made in the CRC for Water Quality and Treatment Hot water services' issues paper (CRCWQT, August 2004).
- *Legionella* monitoring at Café rainwater tank (test site 3) and Ecohouse rainwater tank (test site 9) was undertaken monthly for the period October 2004 –February 2005 as a consequence of recommendations made in the CRC for Water Quality and Treatment Hot water services' issues paper (CRCWQT, August 2004).
- The lack of rainfall during the study period and the initial design of the monitoring program around 'trigger' rainfall events resulted in a reduction in the number of monitoring occasions compared with the number of monitoring occasions initially envisaged.

On line monitoring

A continuous turbidity meter was installed before the UV disinfection unit at the café to asses the rain water turbidity before treatment. A continuous temperature monitoring probe was installed at the outlet of the gas hot water unit to verify whether the hot water temperature can be maintained at 60^{o}C as recommended in the Australian Plumbing Code AS 3500. Turbidity and temperature were logged using a data logger from December 2003 to July 2004. A typical daily variation of turbidity and temperature are shown in Figure 3.18 and 3.19.

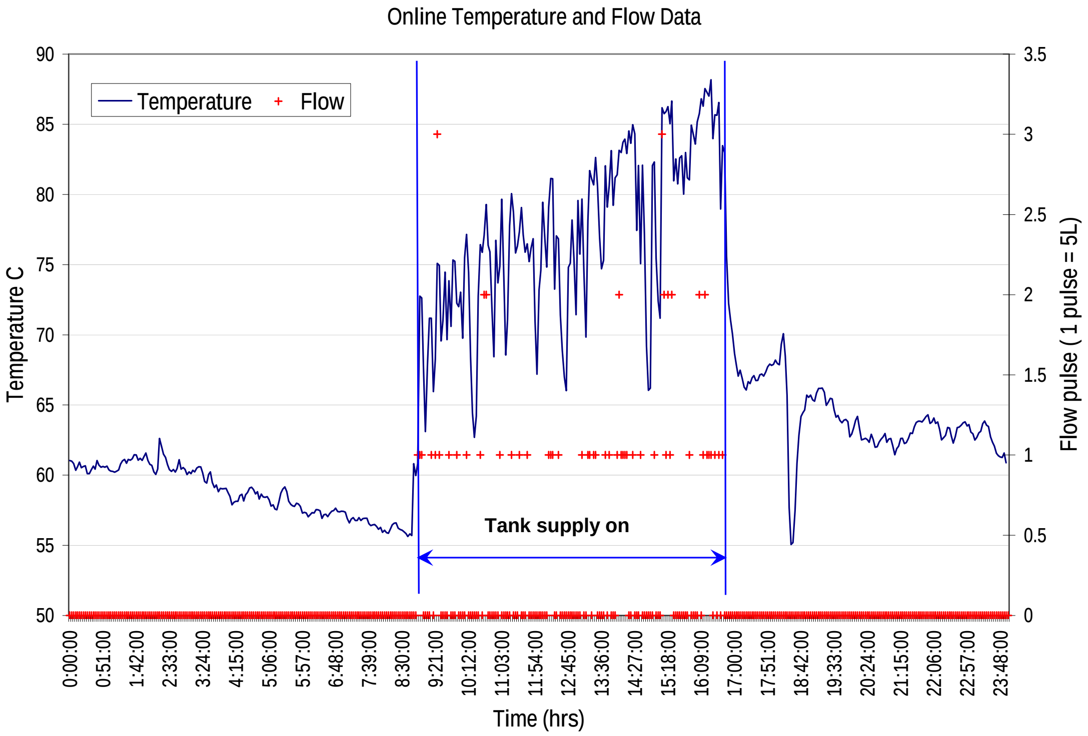


Figure 3.18 Typical daily online temperature and flow data.

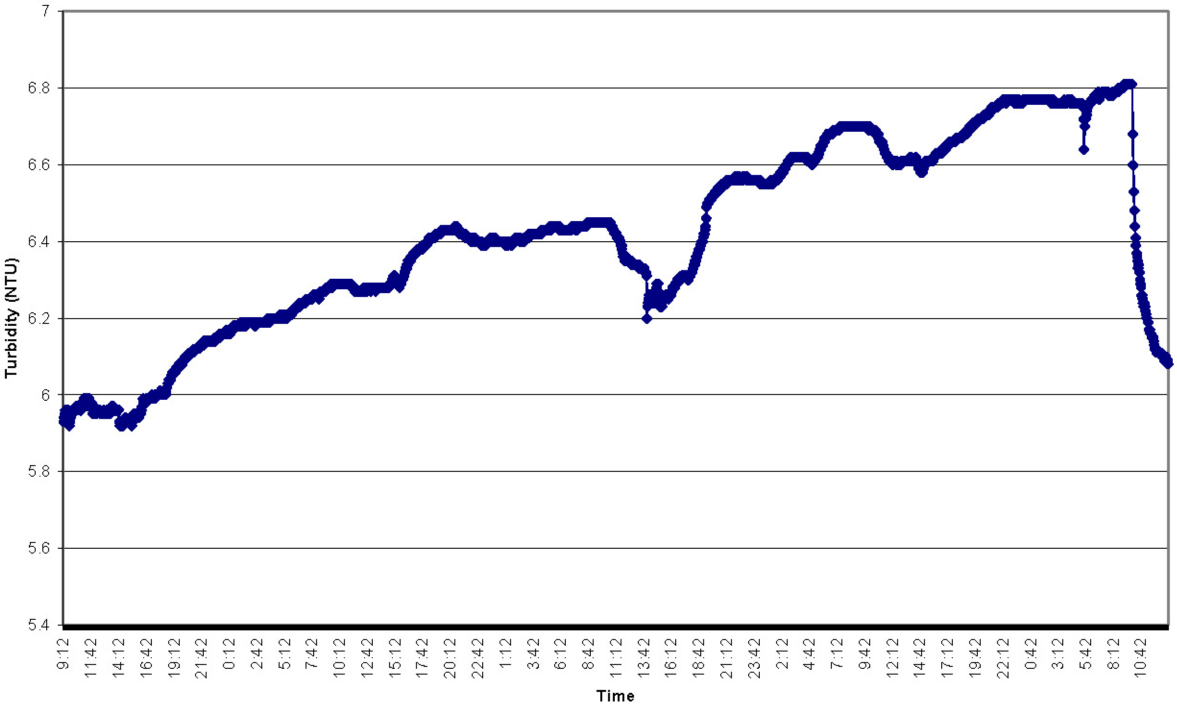


Figure 3.19 Hot water system turbidity data for ~48h period

Chemistry monitoring

During the trial it was evident that the supply from the tank was generally adequate to meet the demand from CERES café for a maximum of two weeks, As a result chemical monitoring frequency was significantly modified only to capture data from rain events. Data from six rain events during the trial are to be presented in this report.

Microbiological monitoring

Table 3.13 summarises the monitoring frequency and the bacteriological parameters tested at each sampling location for the period December 2003 – September 2004. Of note is that the number of monitoring occasions for the rainwater tank at the Café (site 3) and the Ecohouse (site 9) were 16 and 11 respectively as compared with the initial planned program frequency of 52 at each of these sites.

Table 3.13 Microbiological Monitoring Program; CERES, Melbourne.

Test point no.	Location description	Monitoring frequency (period 5/12/03-10/9/04)	Bacteriological parameters monitored
Cafe			
1	Roof runoff prior to filter overflow	Nil	none
2	rainwater tank outlet	16 occasions	• *Aeromonas* • *Campylobacter* • *Clostridium perfringens* • Total coliforms • *E. coli* • Plate count (22°C/72hr) • *Legionella* • *Salmonella*
3	After on-line turbidity meter	1 occasion	• *E. coli* • Total coliforms • Plate count (22°C/72hr)
4	Immediately after UV disinfection	8 occasions	• *E. coli* • Total coliforms • Plate count (22°C/72hr)
5	Hot water at kitchen tap	8 occasions	• *Aeromonas* • *Campylobacter* • *Clostridium perfringens* • Total coliforms • *E. coli* • Plate count (22°C/72hr) • *Legionella* • *Salmonella*
Ecohouse			
6	50L first flush device,	nil	none
7	Rainwater tank scour	nil	none
8	Rainwater tank outlet	11 occasions	• *E. coli* • Total coliforms • Plate count (22°C/72hr) • *Legionella*
9	Post UV unit	nil	none
10	Hot water tap	nil	none

Rainfall trigger

The original water quality monitoring program was developed with the objective of collecting data associated with rain events greater than 5mm. A rainwater sampler was installed to collect samples of rainwater. Microbiological and physical/chemical sampling was planned to occur on a weekly/ monthly basis with the selection of sampling date within this interval influenced by the rainfall trigger.

Laboratory methods

Sample analysis for chemical and microbiological parameters was undertaken by Yarra Valley Water's testing laboratory Ecowise Environmental (Formerly WSL).

3.3.3 Results

Chemical data

Physicochemical parameters

The physicochemical parameters monitored at Melbourne generally yielded results comparable to the National survey data. Again the rainwater is soft, slightly acidic water. The exception to this is the true colour, with the mean from the CERES café tank approximately six times the mean from the National survey data (43 compared to 6.7 respectively). The average ammonia and DOC concentrations are higher in the café tank water compared to the background study data possibly due to the presence of leaves from overhanging tree branches collected on the roof catchment / tank at the café.

Up to 10 samples were tested at the café for physiochemical parameters. This data provides an indication of the variability of results within one system. As evident from the relative standard deviation (rsd), minimum and maximum results shown in Table 3.14, it can be concluded that the variation of data is insignificant.

Table 3.14 Physicochemical parameters tested; CERES café tank (test point 3)

analyte / test	Detection limit	Units	N	Mean	Rsd*	Min	Max
pH	0.1	pH units	5	6.2	27%	5.5	6.8
Alkalinity	1	mg/L	6	4	40%	2	6
Temperature	0.1	º C	10	13.9	32%	10.1	20.5
Turbidity	0.5	N.T.U	9	3.3	26%	1.5	**6.7**
True Colour	2	HU	6	**43**	58%	**30**	**60**
Electrical Conductivity	1	µS/CM	6	47	31%	30	68
Hardness	5	mg/L	6	**8**	8%	**5**	**13**
Total Dissolved Solids	2	mg/L	6	33	34%	17	45
Dissolved Organic Carbon (<0.45um)	1	mg/L	6	6.3	32%	3.6	8.8
TOC	1	mg/L	6	6.9	33%	3.6	10
Ammonia	0.03	mg/L	6	0.18	18%	0.06	0.34

Values in bold lie outside the 2004 ADWG aesthetic values;
*Rsd = relative standard deviation (i.e. the standard deviation expressed as a % of the mean).

pH and anion concentration

A comparison of pH and anion levels was undertaken (Figure 3.20) to assess if nitrous and sulphur oxides have been associated with acidic rain (Gao *et al.* 2001). The results do not indicate significant trend associated with pH and nitrate or sulphate anion concentrations in this tank water (P=0.56). The pH levels rise slightly as rainwater flows through the rainwater harvesting system (from pH= 6.6 in rainwater to pH= 7.3 after hot water system), with small increments at testing points prior to the hot water system. Figure 3.20 shows a rise in sulphates and a drop in nitrates in the roof runoff compared to the levels in rain water. It should be noted that analysis of the roof runoff is based on only one sample.

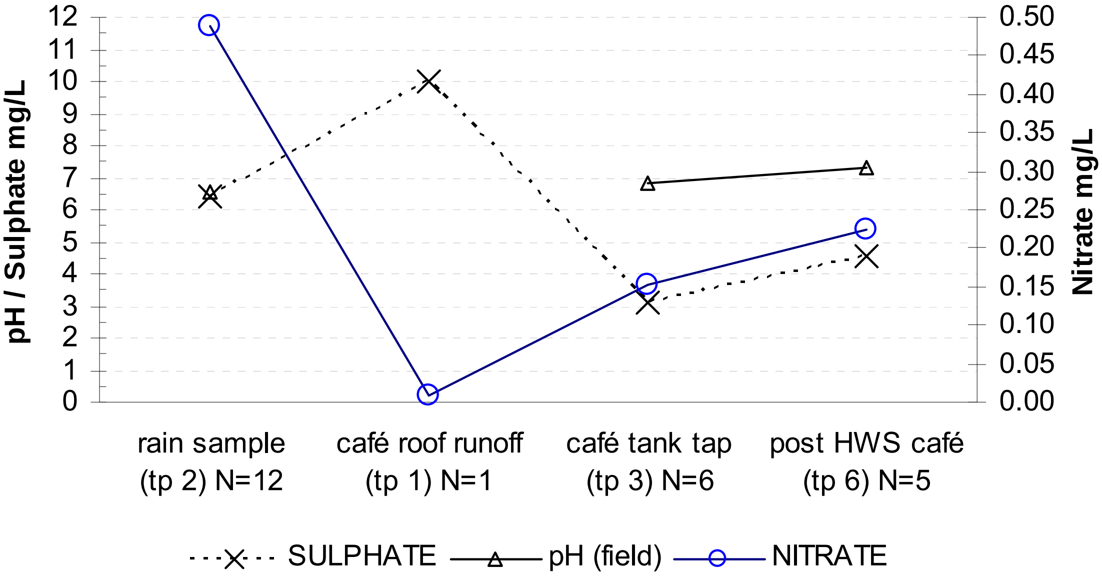


Figure 3.20 Nitrate and sulphate levels Vs pH at different sample points along the rainwater collection system- café at CERES, Melbourne.

Metal concentrations

Minimum, maximum and mean metal and phosphorus concentrations measured in rain from the rain gauge, in roof runoff, at the café tank outlet (test point 3) and after passing through the hot water system. Results for water from the café outlet are given in Table 3.15. Metal concentrations were all below the 2004 ADWG health and aesthetic limits.

The literature review indicated that lead was possibly of concern in tank water and therefore samples for lead analyses were taken from several test points at the café. Lead was shown to be present in the rain fall, however the major input to the Café tanks appears to be from the roof catchment itself (Figure 3.21). This data cannot distinguish between lead leaching from roof materials or associated with the dust that collects on the roof during dry periods.

Given the high concentration of the input and the comparatively low lead concentration of the tank water at the outlet (test point 3) it can be deduced that the lead is removed from the water while in the tanks. This is probably due to settling of particulates that contain or adsorb the lead. Particulate settling would be especially effective given the three tanks are in series. This configuration allows for more particulate removal by sedimentation prior to the outlet at the 3rd tank.

The analytes listed in Table 3.15 were also measured after the water passed through the café hot water system. With the exception of copper and lead there was no significant change post hot water system for all parameters (data not shown). Both copper and lead increased after passage through the hot water system (HWS).

Table 3.15 Mean metal concentrations; CERES café tank

CERES café tank outlet (test point 3)

analyte / test	Detection limit	Units	N	Mean	Min	Max
ALUMINIUM (soluble)	0.005	mg/L	6	0.032	0.007	0.057
CALCIUM	0.1	mg/L	6	1.1	0.1	2.6
COPPER	0.001	mg/L	6	0.011	0.003	0.016
IRON	0.05	mg/L	6	0.12	0.05	0.19
MAGNESIUM	0.001	mg/L	6	1.14	0.55	1.6
MANGANESE	0.001	mg/L	6	0.017	0.003	0.033
PHOSPHORUS (total)	0.005	mg/L	6	0.075	0.058	0.089
LEAD	0.002	mg/L	6	0.005	0.002	0.009

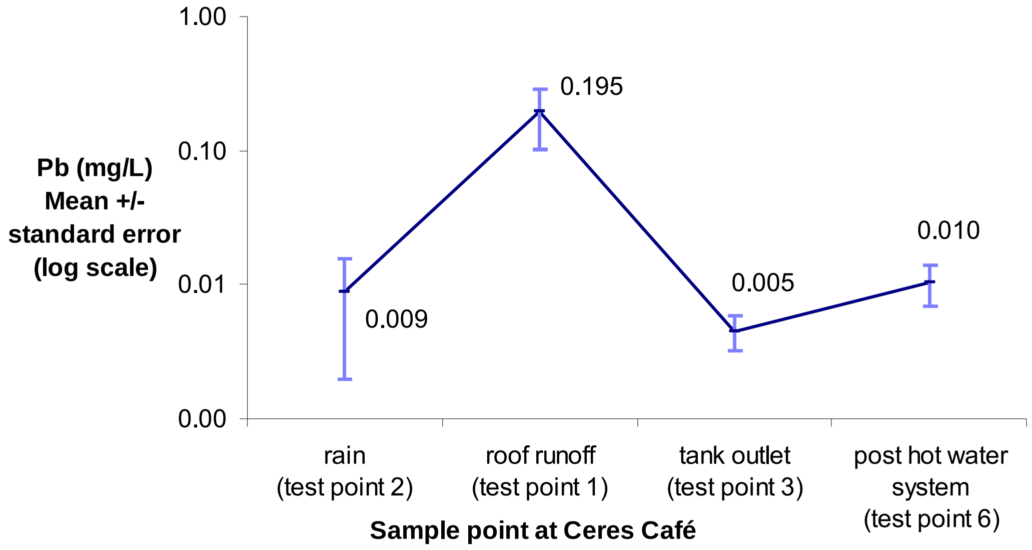


Figure 3.21 Lead concentration (mg/L) ± standard error of the mean for different sample points at the Café, CERES, Melbourne.

Note that the lead concentration is given on a log scale. Detection limit for lead is 0.002 mg/L. N= 12, 9, 6 &5 for test points 2, 1, 3 & 6 respectively.

Organic compounds

Phthalates, BTX, PAHs and a range of Volatile organic compounds (VOCs) were analysed in the CERES Café tank water on 5 separate occasions. The compounds analysed and their respective detection limits are shown in Table 3.16 to Table 3.19. Detection limits for the PAHs and some phthalates were revised during the sampling. However, of the organics tested, none were found in any of the tank samples (test point 3). Rain samples (test point 2) were also tested for BTX and PAHs on 11 occasions and roof runoff (test point 1) on one occasion (data not shown). One rain sample did detect toluene at a level of 1.4µg/L. No other compounds were detected in the rain or roof runoff samples and the toluene found in the rain sample was not detected in the tank water.

Table 3.16 Phthalate compounds tested; CERES café tank

Phthalate compound	Units	Detection Limit
Butyl Benzyl Phthalate	mg/L	0.001
Dibutyl Phthalate	mg/L	0.001
Dichloromethane	mg/L	0.005
Diethyl phthalate	mg/L	0.001-0.01
Dimethyl phthalate	mg/L	0.001-0.01
Di-n-Octyl Phthalate	mg/L	0.001-0.01
Dioctyl Phthalate (di(2-ethylhexyl)phthalate)	mg/L	0.001-0.01

Café tank outlet, none detected, N=5

Table 3.17 BTX compounds tested; CERES café tank

Compound	Units	Detection Limit
Benzene	mg/L	0.001
Bromobenzene	mg/L	0.001
1,2,4-Trimethylbenzene	mg/L	0.001
Chlorobenzene	mg/L	0.001
1,2-Dichlorobenzene	mg/L	0.001
Ethylbenzene	mg/L	0.001
1,3-Dichlorobenzene	mg/L	0.001
1,4-Dichlorobenzene	mg/L	0.001
Toluene	mg/L	0.001
2-Chlorotoluene	mg/L	0.001
4-chlorotoluene	mg/L	0.001
Total Xylenes	mg/L	0.001
Styrene	mg/L	0.001

Café tank outlet, none detected, N=5.

Table 3.18 PAH compounds tested; CERES café tank

Compound	Units	Detection Limit
Cumene	mg/L	0.001
Dibenz(a,h)anthracene	mg/L	0.00001-0.001
Flouranthene	mg/L	0.00001-0.001
Flourene	mg/L	0.00001-0.001
Indeno(1,2,3-CD)pyrene	mg/L	0.00001-0.001
Napthalene	mg/L	0.00001-0.001
Phenanthrene	mg/L	0.00001-0.001
Pyrene	mg/L	0.00001-0.001
Acenaphthene	mg/L	0.00001-0.001
Acenaphthalene	mg/L	0.00001-0.001
Anthracene	mg/L	0.00001-0.001
Benz(a)anthracene	mg/L	0.00001-0.001
Benz(b)flouranthene	mg/L	0.00001-0.001
Benzo(a)pyrene	mg/L	0.00001-0.001
Benzo(g,h,i)perylene	mg/L	0.00001-0.001
Benzo(k)flouroanthene	mg/L	0.00001-0.001
chrysene	mg/L	0.00001-0.001
Total PAHs	mg/L	0.003

Café tank outlet, none detected, N=5.

Table 3.19 Volatile Organic Compounds tested; CERES café tank

Volatile organic compound	Units	Detection Limit
1,1,1,2-Tetrachloroethane	mg/L	0.001
1,1,1-Trichloroethane	mg/L	0.001
1,1,2,2-Tetrachloroethane	mg/L	0.001
1,1,2-Trichloroethane	mg/L	0.001
1,1- Dichloroethane	mg/L	0.001
1,1-Dichloroethene	mg/L	0.001
1,1-Dichloropropene	mg/L	0.001
1,2,3-trichloropropane	mg/L	0.001
1,2-dibromo-3-chloropropane	mg/L	0.001
1,2-dibromoethane	mg/L	0.001
1,2-Dichloroethene [cis]	mg/L	0.001
1,2-Dichloroethene [trans]	mg/L	0.001
1,2-Dichloroethane	mg/L	0.001
1,2-Dichloropropane	mg/L	0.001
1,3-Dichloropropane	mg/L	0.001
1,3-Dichloropropene [cis]	mg/L	0.001
1,3-Dichloropropene [trans]	mg/L	0.001
2,2-Dichloropropane	mg/L	0.001
Bromochloromethane	mg/L	0.001
Dibromomethane	mg/L	0.001
Carbon Tetrachloride	mg/L	0.001
bromodichloromethane	mg/L	0.001
bromoform	mg/L	0.001
chlorodibromomethane	mg/L	0.001
chloroform	mg/L	0.001
Tetrachloroethene	mg/L	0.001
Trichloroethene (Trichloroethylene)	mg/L	0.001
Vinyl Chloride (Monomer)	mg/L	0.01

Café tank outlet, none detected, N=5.

Microbiological data

Presentation and discussion of microbiological results is divided into three parts. Firstly, results for the microbiological quality of rainwater tank water at the Café and the Ecohouse are presented and discussed.

Secondly, microbiological results for the site immediately post UV disinfection are presented (test point 5). These results are segmented into two parts:

(a) where the UV irradiation unit was documented as having been turned off; and

(b) where the UV irradiation unit was documented as being operative.

Finally, results for the hot water kitchen tap at Ceres Café (test point 6) are also presented and discussed. These results enable a discussion of the impact of elevated hot water temperatures on the prevalence of micro-organisms. Results of temperature monitoring of stored water in the pre-feed tank to the hot water system heated by a solar system and in the final hot water tank (heated using a gas ‘Aquamax’ system) are also referred to in the discussion of results.

Rainwater tank microbiological quality

Bacteriological results for the period 5/12/03-10/9/04 are shown in Table 3.20 for the two rainwater tanks at CERES. Results for *Salmonella* and *Campylobacter* are not shown in the table as neither pathogen was detected in the rainwater tank at the Café on the (eight samples) and the Ecohouse (6 samples).

Results show the presence of *E. coli*, total coliforms, *Aeromonas*, *Clostridium perfringens* and plate count bacteria in all samples at both rainwater tanks. The presence of *E. coli* indicates faecal contamination of rainwater tank water. Total coliforms detected on each monitoring occasion may have originated from faecal contamination and/or from environmental contamination (soil and vegetation) of the tank water. The presence of *Clostridium perfringens* and *Aeromonas* bacteria is not unexpected given the ubiquity of these organisms in the environment. High numbers of plate count bacteria detected in both tanks are possibly associated with one or more factors including low turnover of water in the tank, high input of vegetative matter on which bacteria are able to grow and multiply and build-up of sediment in the tank also supplying nutrients for bacterial growth. The presence of high numbers of both *Aeromonas* and total coliforms on occasions indicates potential microbial re-growth within the rain water tank water.

No *Legionella* bacteria were detected in the rainwater tank at the Café on any of the 10 monitoring occasions at the level of method detection (<10 organisms/mL for the period 5/12/03 -3/9/04 and <100/L for January 2005 onwards (N=2)). No *Legionella* bacteria were detected at the Ecohouse on the 2 monitoring occasions during the period 5/12/03 - 3/9/04 nor for the monitoring occasions after January 2005 (N=2).

Table 3.20 Bacteriological quality of rainwater tank water at CERES

Location	Summary statistic	*Aeromonas* orgs/ 100mL	*C. perfringens* orgs/ 100mL	Total coliforms orgs/ 100mL	*E. coli* orgs/ 100mL	Enterococci orgs/ 100mL	Plate count (22oC/ 48hrs) orgs/mL
Rainwater tank Café (test site3)	Prevalence Median Nº samples Range	100% 85 4 10-42,000	100% 21 7 4-53	100% 375 16 3-2,400	100% 27 16 1-2,400	80% 4 5 0-72	100% 3800 16 1-100,000
Rainwater tank Ecohouse (test site9)	Prevalence Median Nº samples Range	NA	NA	100% 2200 11 200-2,400	100% 200 11 2-2,000	na	100% 1600 11 1-72,000
Overall	Prevalence Median Nº samples Range	100% 85 4 10-42,000	100% 21 7 4-53	100% 460 27 3-2,400	100% 160 27 1-2,400	80% 4 5 0-72	100% 2800 27 1-100,000

Key: NA = not applicable

UV irradiation

One of the objectives of the CERES water quality trial was to specifically investigate the harvesting of rainwater for hot water and the impact of UV disinfection as a supplementary treatment process. To this end the monitoring period included a period where the UV disinfection unit was turned off. Table 3.21 gives a summary of results for test point 5 (post UV irradiation treatment point) for the period where UV unit was documented as being 'off' (18/8/2004-10/9/2004). These results show, not unexpectedly, the survival of *E. coli* and coliform bacteria when the UV unit is turned off.

Table 3.21 Microbiological quality at test point 5 Ceres Café with UV treatment unit not operative

Parameter	Prevalence	No samples	Median	Range
Coliforms /100mL	100%	3	230	190-250
E. coli /100mL	100%	3	29	16-110
HPC (22^{o}C / 72hrs) orgs/mL	100%	3	430	230-1,300

Table 3.22 summarises results for test point 5 (Post UV irradiation treatment point) for period where UV unit was documented as being 'on' (5/12/2003 -12/8/2004). These results show that during the period where the UV unit was documented as being operative, that the UV irradiation process was not continuously effective. It is well established in the scientific literature that *E. coli* and coliform bacteria

are inactivated by a properly operating UV irradiation process. The presence of *E. coli* and coliform bacteria post UV irradiation thus may have been attributed to a number of reasons:

- The UV unit was turned off at times during the monitoring period (i.e. it was not continuously operative) or the unit was erroneously assumed to be 'on' when this was not the case
- A 'bolus' of turbid water or coloured water may have interfered with the disinfection process
- Ineffective UV treatment associated with water flows, UV transmission reading of the water, dirty UV lamps, etc

Clearly, during the period when the UV was documented as being 'on' there were occasions where non irradiated water was being supplied to the hot water tank. During the period 5/12/03 – 12/8/04 there were only 2 occasions that bacterial indicator results indicated that UV irradiation was effective (12-8-04 and 16-4-04).

Table 3.22 Microbiological quality at test point 5 where UV treatment is documented as being operative

Parameter	**Prevalence**	**No samples**	**Median**	**Range**
Coliforms	60%	5	2	0-34
E.coli	20%	5	0	0-10
Plate count 22^{o}C / 72hrs	80%	5	60	0-320

Hot water

The impact of hot water temperatures on the inactivation of micro-organisms may be established by comparing the microbiological quality of water at test point 5 (rainwater after UV treatment and pre-hot water system) and test point 6 (hot water kitchen tap i.e. post hot water system). However, only those results for test site 5 where the UV unit was not operating (i.e. turned off or ineffective operation) are able to be used in this evaluation. Taking results at test point 5 where the UV unit was not operative and combining them with results for test point 5 where the UV unit was documented as being 'on' but where indicator results indicated ineffective UV disinfection there are 5 pairs of results (28/5/04, 2/7/04, 18/8/04, 1/9/04, 3/9/04) which enable assessment of the performance of the hot water unit in removing indicator bacteria. On each of these occasions, results at the hot water kitchen tap show that maintaining water temperature at 60^{o}C in the hot water unit was adequate to remove/ destruct indicator bacteria. A summary of microbiological results for the hot water at the kitchen tap at CERES (UV unit not operating or not operating effectively) are given in Table 3.23. Results for *Salmonella, Campylobacter* and *Legionella* are not shown in the table as neither pathogen was detected in the hot water at the Café kitchen tap on the 6, 5 and 12 occasions respectively that monitoring for these pathogens was performed.

Table 3.23 Microbiological quality of hot water at Café kitchen tap (UV unit not operative)

Summary statistic	*Aeromonas* orgs/ 100mL	*C. perfringens* orgs/ 100mL	Total coliforms orgs/100mL	*E. coli* orgs/ 100mL	Enterococci orgs/ 100mL	Plate count (22^{o}C/48hrs) orgs/mL
Prevalence	100%	86%	0%	0%	0%	38%
Median	10	2	NA	NA	NA	30
N^o samples	6	6	7	7	4	7
Range	10-50	0-23	na	na	na	0-5,60

Key: NA = not applicable

These results allow the conclusion to be drawn that maintaining hot water temperature at 60°C (the hot water setting at the Café) would be sufficient to inactivate/ remove indicator bacteria of *E. coli* and coliforms. This is in accord with scientific literature. Data at CERES does not allow the direct observation that hot water temperature at CERES achieves the removal of *Campylobacter* and *Salmonella* bacteria (these bacteria were not detected in the rainwater tank water at the Café hence their inactivation cannot be assessed). However as these bacteria have documented similar (or lesser) thermal resistance than indicator bacteria, based on indicator results at the hot water kitchen tap, inactivation of these bacteria can also be assumed.

The presence of *Aeromonas* in hot water at the kitchen tap (prevalence 100%) is unexpected based on the lesser thermal resistance of these bacteria compared with the non-detection of *E. coli* in kitchen tap water. Given the documented sensitivity of *Aeromonas* to heat treatment, possible explanations for their presence in the hot water at the kitchen tap is that they have originated from the conventional drinking water supply and /or post water treatment contamination of rainwater supply system and growth within the rainwater harvesting system (monitoring for *Aeromonas* bacteria in the drinking water supply was not undertaken). *Aeromonas* bacteria are nutritionally versatile and may multiply in distribution systems. Numbers of *Aeromonas* detected at the hot water tap are low and in the context of numbers found in Australian reticulated drinking water supplies, do not present a health risk.

In contrast, the survival of *Clostridium perfringens* post hot water treatment (prevalence 86%) is to be expected due to the thermal resistance of Clostridial spores. For example, detection methodology for *Clostridium perfringens* includes a heating step above 60°C to select for spores of sulphite reducing *Clostridia*. In addition, the presence of *Clostridium perfringens* in water does not present a direct health risk. It is only in circumstances where water containing Clostridial spores is used for food production and where optimal growth conditions (nutrients and temperature) are present (allowing multiplication of bacteria to high numbers) that a potential (but low probability) health risk may ensue.

From the microbiological data set available, it is not possible to deduce the inactivation of *Legionella* on the basis of non-detection of *E. coli* and coliform bacteria in hot water at the kitchen tap. This is because both *E. coli* and coliform bacteria are significantly more temperature sensitive compared with *Legionella.*

In relation to use of roof collected rainwater for domestic hot water systems and the risk of legionellosis, current Australian regulations relating to hot water storage temperature (provided that they are followed) are regarded as an effective intervention measure for the control of *Legionella* bacteria irrespective of the source of water for domestic use. Temperature monitoring data of stored hot water at the CERES Café shows compliance with these guidelines.

Stored hot water temperatures

Results for this continuous on-line (every 3 seconds) monitoring show that during the monitoring period (02/05/2006-14/06/2005) stored water temperatures in the solar hot water pre-heater were generally in the range 15°C-25°C and that excursions in temperature above 35°C were rare. For the stored gas heated hot water, temperatures were above 50°C on all except a few monitoring occasions and the temperature range was generally between 55°C and 90°C. From the viewpoint of an intervention measure to restrict the proliferation of *Legionella* bacteria, this temperature data shows that the CERES Café hot water temperature set point (60°C) allowing for the cycling between night and day ambient temperatures, consistently achieves a hot water temperature in excess of 55°C with periods where stored hot water temperature are significantly above 70°C. Thus, temperature time combinations afforded by stored hot water under these conditions are effective in achieving bacterial kill of *Legionella* bacteria. Even in the event that solar pre-heating gives rise to potential *Legionella* proliferation, the subsequent heating measure ensures bacterial kill.

3.3.4 Conclusions

- The presence of the faecal indicator bacterium, *E. coli* in rainwater tank water on all monitoring occasions is consistent with the susceptibility of both roof catchments at CERES to faecal contamination from small animals and birds. The presence of *E. coli* indicates the potential presence of enteric pathogens in tank water.

- The failure to detect typical enteric pathogens *Campylobacter* and *Salmonella* may be related to the sporadic carriage of these micro-organisms by birds / animals or the infrequency of monitoring. The failure to detect these micro-organisms on each of the monitoring occasions does not imply their continuous absence from tank water and it is possible that the detection methodology employed does not detect all species of bacteria from these genera.

- The presence of *Clostridium perfringens* and *Aeromonas* bacteria on all monitoring occasions at both tanks is not unexpected given the ubiquity of these organisms in the environment (soil, vegetation etc). In addition, *Aeromonas* is nutritionally versatile and bacterial growth may occur associated with nutrient loading of the rainwater tank water.

- High numbers of plate count bacteria (22^{o}C/72hrs) detected in both tanks are potentially associated with one or more factors including low turnover of water in the tank, high input of vegetative matter on which bacteria are able to grow and multiply and build-up of sediment in the tank also supplying nutrients for bacterial growth. The presence of both high numbers of *Aeromonas* and total coliforms on occasions indicates potential microbial re-growth within the rain water tank water.

- UV irradiation is not required, in addition to heating in the hot water unit, to achieve removal of faecal indicator bacteria, *E. coli* and coliforms and for micro-organisms with a similar (or lesser) thermal resistance (i.e. *Salmonella*, *Campylobacter* and *Aeromonas*).

- Overall the nature of the potential microbiological health risks and the importance of the different exposure routes are not intrinsically different for rainwater and conventional tap supplies. Rainwater tank results for CERES show that water from rainwater tanks is more variable in microbial quality compared with conventional tap water supplies.

- The redundancy or otherwise of the UV irradiation treatment process at CERES cannot be established from available data due to the limitations of the monitoring program.

- The focus of health concern in relation to the use of rainwater for a hot water supply is those micro-organisms that are able to survive hot water temperatures which may cause illness. Where changes to hot water storage temperatures and hot water unit operation are contemplated as energy saving measures, it is important that the adequacy of the selected temperature and time to inactivate all micro-organisms of health concern is verified. In addition, the implications of a reduction in hot water storage temperature and/ or the need for particular intervention measures (e.g. UV irradiation) for the susceptible sub group within the general population needs to be established.

- Physicochemical properties of the tank water are not markedly different from other locations (i.e. soft and slightly acidic water) apart from leaves from overhanging trees leading to higher dissolved organic carbon and true colour in the water.

- Detection of lead in rain water prior to reaching the roof catchment shows atmospheric pollution from lead. However, there is a much larger input from the roof itself for the elevated levels of lead. The source of the lead from the roof requires further investigations.

- Despite relatively high lead inputs to the tank, the water at the outlet still meets the 2004 ADWG. This is probably due to the configuration of the three tanks at the Café allowing settling of particulates which contain or adsorb the lead.

3.4 Mutitjulu (Northern Territory)

3.4.1 Introduction

The rainwater harvesting project at Mutitjulu project was conducted under the joint auspices of the Centre for Appropriate Technology (CAT), Cooperative Research Centre for Water Quality and Treatment and the Aboriginal and Torres Strait Islander Commission (ATSIC). The project commenced in June 2002 and water quality monitoring was completed in June 2004.

Mutitjulu is a community of approximately 350 Indigenous people located at the base of Uluru, Central Australia. The water source for the community is groundwater. Drinking water is preferred to groundwater by communities because of its improved palatability. One of the objectives of this project was to understand the possible health risks associated with drinking water from rainwater tanks and to broadly quantify the level of risk, which would be lowered by the introduction of an appropriate point of use (POU) device.

Water quality monitoring included bacteriological analysis of rainwater tank water before and after the POU device. Only the bacteriological results for the rainwater tank water prior to the POU device are presented here.

3.4.2 Methods

Rainwater tank characteristics

Seven rainwater tanks were installed on newly constructed houses at Mutitjulu with appropriate guttering, pump, piping and taps to deliver rainwater into kitchens for drinking purposes. All houses have sampling taps before and after POU devices external to the house. Some house occupants prefer to sleep outside and use the post treatment sampling tap to access the drinking water supply.

Characteristics of each of the tanks monitored for bacteriological parameters are given in Table 3.24 below.

Table 3.24 Rainwater tank characteristics at Mutitjulu

Volume	Settling tank = 500 L plus 2 x 8000L capacity tanks (with maximum water volume of 6000L for each tank associated with location of inlet and outlet pipes)
Material	Polycarbonate, beige colour
Roof area	250m^2
Outlet tap	All tanks are connected to indoor kitchen tap; houses also have pre- and post – POU device taps for sampling outside

Microbiological Monitoring

The initial project brief included provision for bacteriological monitoring of rainwater tank water on a quarterly basis and after each major rain event. This was not always possible given logistic considerations (e.g. the travel time to Mutitjulu, airline schedules, laboratory availability and capabilities etc). Bacteriological monitoring performed comprised testing for faecal coliforms and / or *E. coli* and sulphite reducing *Clostridia* / *Clostridium perfringens*. Testing for plate count organisms (37°C/24hrs) and coliforms, although outside the project brief, was performed on one occasion based upon the capabilities of the testing laboratory and the 'usual' suite of bacteriological parameters tested for by this laboratory.

Testing was initially performed by the Australian Water Quality Centre, South Australia (one monitoring) but later monitorings were performed by the Water Microbiology Laboratory Department Business, Industry and Resources Development, Northern Territory (one monitoring) and Ecowise Environmental, ACT (two monitorings).

At the outset of the project it was envisaged that rainwater tank water at all 7 houses would be monitored. However, this did not occur initially because not all tanks had enough water for sampling.

The variability in water storage was due to poor construction. There was a lengthy process with contractors and project managers to make rectifications. The high mobility of household residents made continuity of the management and care of the infrastructure difficult. During the first 12 months of house occupation, 3 households remained constant and 4 houses changed occupants completely (some of these houses had multiple complete changes). Two houses were empty for extended periods and one house for more than 6 months. The variations in household occupancy meant that the planned sampling regime could not be executed exactly. For example, visitors had damaged infrastructure and sampling was not possible or it was not culturally appropriate to enter a property because of mourning.

The rationale for selection of monitoring parameters and the methodology employed are given in Table 3.25.

Table 3.25 Rationale for selection of microbiological parameters

Parameter	Rationale for selection	Method
E. coli	Indicator of faecal pollution of the rainwater	APHA Standard Methods *E. coli* 9222D
Clostridium perfringens	Surrogate for the removal of *Cryptosporidium* spores by POU filtration device	AS4276.17.1

The monitoring dates, number of tanks monitored, houses monitored, testing laboratory and parameters tested are given in Table 3.26.

Table 3.26 Monitoring details at Mutitjulu

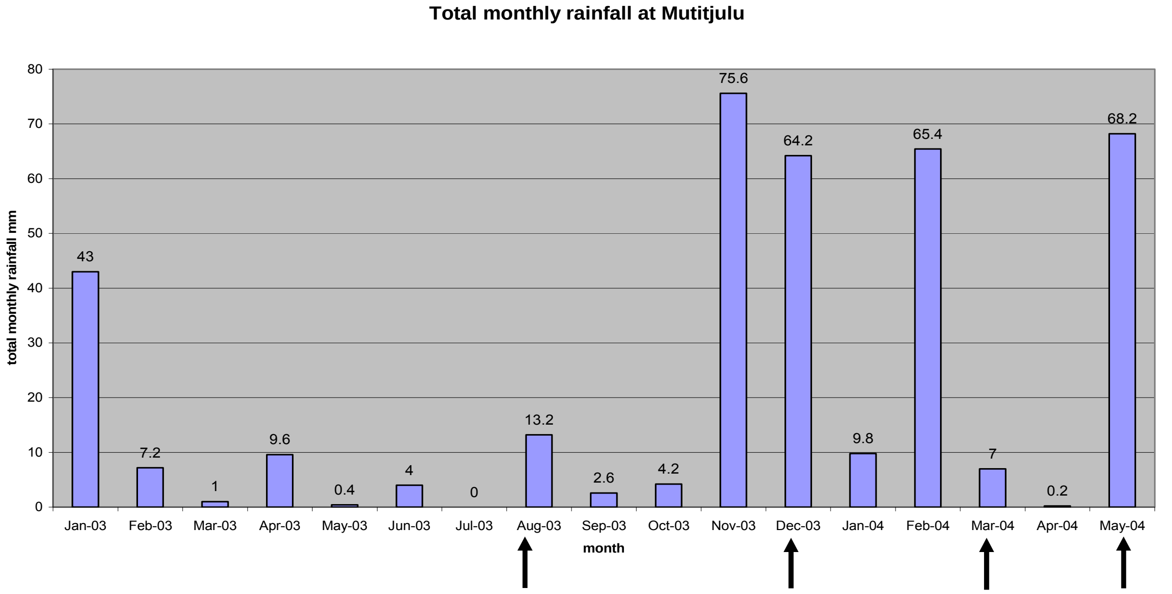
Monitoring date	No. tanks tested	House Nos tested	Parameters tested for	Laboratory undertaking monitoring
7th Aug 2003	3	Houses 84, 85, 91	*E. coli* Sulfite reducing *Clostridia* *C. perfringens*	AWQC (SA)
9th Dec 2003	5	Houses 82, 84, 85, 89, 91	*E. coli* Total coliforms Faecal coliforms Plate count (37°C/48hrs)	Dept Business, Industry & Resource Development (NT)
8th Mar 2004	6	Houses 81, 84, 85, 89, 91, 92	*E. coli* Faecal coliforms *C. perfringens*	Ecowise Environmental (ACT)
19th May 2004	5	Houses 81, 84, 85, 91, 92	*E. coli* Faecal coliforms *C. perfringens*	Ecowise Environmental (ACT)

A total of seven different rainwater tanks were monitored for bacteriological parameters during the study. Three rainwater tanks (houses 84, 85 and 91) were monitored on 4 occasions, three rainwater tanks (houses 89, 91 and 92) were monitored on two occasions and one rainwater tank (house 82) was monitored on one occasion only.

3.4.3 Results

Rainfall data

Figure 3.22 gives available total monthly rainfall data for Mutitjulu (Bureau of Meteorology rainfall data, Yulara, NT) for the study duration, the dates on which monitoring occurred and the amount of rainfall in the 24 hrs preceding each monitoring event.



7th August monitoring, 0mm rain 24hrs prior

9th Dec monitoring, 0mm rain 24hr prior

8th March monitoring, 0mm rain 24hr prior

19th May monitoring, 41.5mm 24hrs prior

Figure 3.22 Total monthly rainfall at Mutitjulu for period Jan 03 - May 04

On three of the four occasions that monitoring was performed there was no rainfall in the 24 hrs immediately prior to sampling. For the monitoring of May 19th 2004, 41.4 mm rain fell in the 24 hrs prior to monitoring and this represented some 61 % of rainfall for that month.

An overall summary of bacteriological results (all sites) is given in Table 3.27. *E. coli* results for the monitoring of the 7th August 2003 are not included in the analysis on the basis that samples were 2 days old when analysed at the laboratory. *E. coli* counts reported by the laboratory thus may be an underestimate of actual counts as a consequence of bacterial die-off during sample transit. However, results for sulphite reducing *Clostridia* / *C. perfringens* have been included based upon their prolonged survival in water samples and the likelihood of the maintenance of their numbers in the water sample during the extended sample transit period.

Table 3.27 Bacteriological results: Mutitjulu

Parameter	N	Prevalence	Median	Range
Sulphite reducing *Clostridia* / 100mL	14	57%	3	0-320
C. perfringens / 100mL	14	0%	NA	NA
E. coli / 100mL	16	6%	0	0-18
Faecal coliforms / 100mL	16	6%	0	0-18
Plate count orgs/mL (37°C/48hr)	5	100%	5200	3200-10000+
Total coliforms / 100mL	5	20%	0	0-20

Key: NA = not applicable

Overall results show a low prevalence of *E. coli* / faecal coliforms in rainwater tank samples (6%, N=16) and corresponding low median counts. In fact, *E. coli* / faecal coliforms were detected in only one rainwater tank (house number 82) during the entire monitoring period. The presence of faecal indicator bacteria at this site, but not at other sites, indicates recent faecal contamination of water in this tank, possibly associated with peculiarities of this roof catchment. No specific details with respect to this tank roof catchment (e.g. presence of animal faecal droppings, household debris) were recorded. The rainwater tank at house 82 was monitored on only one occasion and there is no follow-up bacteriological data for this site. Of note is that on the occasion *E. coli* was detected, no rainfall in the 24hrs prior to sampling was recorded. In addition, no rainfall was recorded for the period 1st -7th August nor for July 2003 at the Yulara recording station.

One possible reason for the low overall prevalence rate of *E. coli* in rainwater tank water at Mutitjulu may be the low frequency of access by birds and small animals to the roof catchments. In addition, even when faecal matter is deposited on the roof; die-off of faecal bacteria on the roof catchment may occur as a consequence of UV irradiation and other mechanisms (heat, desiccation etc), consistent with harsh climatic conditions. Furthermore, the opportunity for bacterial die-off occurring on the roof catchment is enhanced when the period between rainfall events is extended. High water temperatures may also result in the rapid die-off of *E. coli* bacteria in the tank water itself.

The prevalence of sulphite reducing *Clostridia* of 57% in rainwater tank water for all monitorings (N= 14) is not unexpected given the ubiquity of sulphite reducing spores in the environment (e.g. soil etc) and their ability to withstand elevated temperatures. Analysis for sulphite reducing *Clostridia* is based on characteristics readily identified in operational terms and is the preamble step to the identification of *Clostridium perfringens*.

Identification of *Clostridium perfringens* from the larger group of sulphite reducing *Clostridia* is based on 'stormy clot' production in litmus milk. *C. perfringens* is regarded as a more sensitive indicator of faecal contamination than the sulphite reducing *Clostridia* group as a whole. *C. perfringens* was not detected in any of the samples. Whilst the absence of *C. perfringens* in drinking waters does not preclude the presence of other indicators and pathogens, taken in the context of corresponding *E. coli* / faecal coliform counts, *C. perfringens* results support the conclusion that, with the exception of one rainwater tank (house number 82), there was no evidence of faecal contamination of tank water. On the one occasion, *E. coli* was detected in the rainwater tank water, analysis for either sulphite reducing *Clostridia* or *C. perfringens* was not performed.

High numbers of plate count results recorded for each of the tanks are consistent with low turnover water and / or the potential build-up of sediment supplying nutrients on which bacteria may grow and multiply.

Water temperature

No water temperature data is available for the Mutitjulu rainwater tanks. Water temperature may be an important factor in the die-off of faecal pathogens in rainwater tank water at Mutitjulu and may account, at least in part, for the low prevalence rate of faecal indicator bacteria. Conversely, higher water temperatures (e.g. above 25°C) may also be a factor leading to higher numbers of some bacteria (e.g. some plate count bacteria, *Legionella* species etc) as a consequence of bacterial amplification in the tank water. A previous study of the microbiological quality of drinking water in four communities in the Anangu Pitjatjanjara Lands in the far north west of South Australia (Plazinska 2000) found a correlation between black poly tanks and higher bacterial growth.

It would be of interest to record the temperature profiles of water in rainwater tanks at Mutitjulu to ascertain whether water temperature is continuously in a favourable range for the amplification of some bacteria (e.g. *Legionella* species). Also, monitoring of water temperature in Mutitjulu rainwater tanks would enable a comparison to be made between rainwater tank water temperatures in beige poly tanks as compared with black poly tanks in the same locality to quantify the impact of this design measure.

Available temperature data from the Anangu Pitjatjanjara Lands Rainwater tank audit and microbiological survey conducted in 2000 (Nganampa Health Council & AIATSIS data shows that mean tank water temperatures (water monitored during the day in the period 1025hr to 1820hr and during the period 9/3-14/4/2000) ranged from 23.8°C -27.4°C, depending on the location of the tank relative to the house (north side or other) and whether the tank was shaded (all and part of the day) or in full sun. Highest maximum temperatures were recorded for tanks on the north side and in full sun (30.5°C). The minimum recorded temperature recorded was 19°C for all locations. Analysis of results for poly tanks only (constituting some 47% of the tanks surveyed for water temperature) shows a mean temperature range for different locations of 23.3°C-27.7°C. The highest temperature recorded was 30°C for tanks located on the north side and in full sun. Results are presented in Table 3.28.

Table 3.28 Water temperature monitoring data: Anangu Pitjatjanjara Lands rainwater tanks

Tank type	**location**	**Sun/ shade**	**Mean temp (°C)**	**N**	**Range (°C)**	**Mean volume water in tank (L)**	**% full**
Polyblack	North side	Sun	24.4	20	19-30	11,410	77%
	North side	Shade	25.4	6	21-28	21,243	92%
	Other side	Sun	27.7	3	27-28.5	6,781	80%
	Other side	shade	23.3	19	20-28	6,026	84%
	All	**All**	**24.3**	**48**	**19-28.5**	**10,484**	**82%**
All tanks	North side	Sun	24.4	33	19-30.5	10,462	80%
	North side	Shade	25.2	12	19-28	16,306	85%
	Other side	Sun	27.4	11	21-30	9,086	78%
	Other side	shade	23.8	47	18-30	10,705	83%
Overall	**All**	**all**	**24.4**	**103**	**18-30.5**	**11,087**	**82%**

Source of data: Nganampa Health Council and AIATSIS

3.4.4 Conclusions and Recommendations

The following conclusions may be drawn from the bacteriological data for rainwater tank monitoring at Mutitjulu:

- Data collected provides a limited ‘snap shot’ of rainwater tank bacteriological quality at Mutitjulu.
- Bacteriological results for those rainwater tank waters monitored on more than one occasion, showed a continued absence of *E. coli* bacteria, irrespective of whether rainfall was recorded in the 24hrs prior to monitoring or not.
- Of the four monitoring occasions, there was only one occasion that rain fell in the 24hrs prior to sampling.
- Despite the significant rainfall event (41.5 mm equivalent to 61% of the monthly total) in the 24hrs prior to the monitoring of 19th May 2004, no faecal bacteria were detected in the rainwater tank waters monitored on this occasion (houses 81, 84, 85, 91 and 92).
- Only one rainwater tank water sample showed evidence of faecal contamination (house 82) and this rainwater tank was monitored on a single occasion.
- The low overall prevalence rate of *E. coli* in rainwater tank water at Mutitjulu possibly may be associated with the low frequency of access by birds and small animals to the roof catchments. In addition, even when faecal matter is deposited on the roof; die-off of faecal bacteria on the roof catchment may occur as a consequence of UV irradiation and other mechanisms (heat, desiccation etc), consistent with harsh climatic conditions. Furthermore, the opportunity for bacterial die-off occurring on the roof catchment is enhanced when the period between rainfall events is extended. High water temperatures may also result in the rapid die-off of *E. coli* bacteria in the tank water itself.
- High levels of plate count bacteria which were enumerated on only one monitoring occasion (7th August 2003) are consistent with low turnover water and / or the potential build-up in the rainwater tank of sediment, supplying nutrients on which bacteria may grow and multiply.

As an extension to the Mutitjulu project, it is recommended that the temperature profiles of water in rainwater tanks at Mutitjulu be recorded during both 'representative' summer and winter periods. This could be achieved by the selection of sentinel tank(s) at Mutitjulu where water temperature is measured each day at 6 hourly time intervals (e.g. 0600hr, 1200hr and 1800hr) for a 2-4 week period. This information will enable it to be ascertained whether water temperature during summer and winter periods is maintained in a favourable range for an extended period to allow the amplification of some bacteria (e.g. *Legionella* species). Also, monitoring of water temperature in Mutitjulu rainwater tanks will enable a comparison to be made between rainwater tank water temperatures in beige poly tanks as compared with black poly tanks in the same locality (data for black poly tanks available – Plazinska 2000) to quantify the impact of this design measure.

3.5 Temperature profiling from the Healthy Home study Queensland

Work has previously been conducted by the Department of Natural Resources Mines and Energy as part of the Healthy Home project. Temperature monitoring of the solar heated hot water was performed as part of the Healthy Home project (Gardner and Miller, *pers. Comm.).* This monitoring included hot water temperature monitoring not only for periods when the booster heater was turned on (set temperature 60°C) but also during periods when it was switched off. Results for September and February for solar heated water with the booster turned off are shown diagrammatically in Figure 3.23.

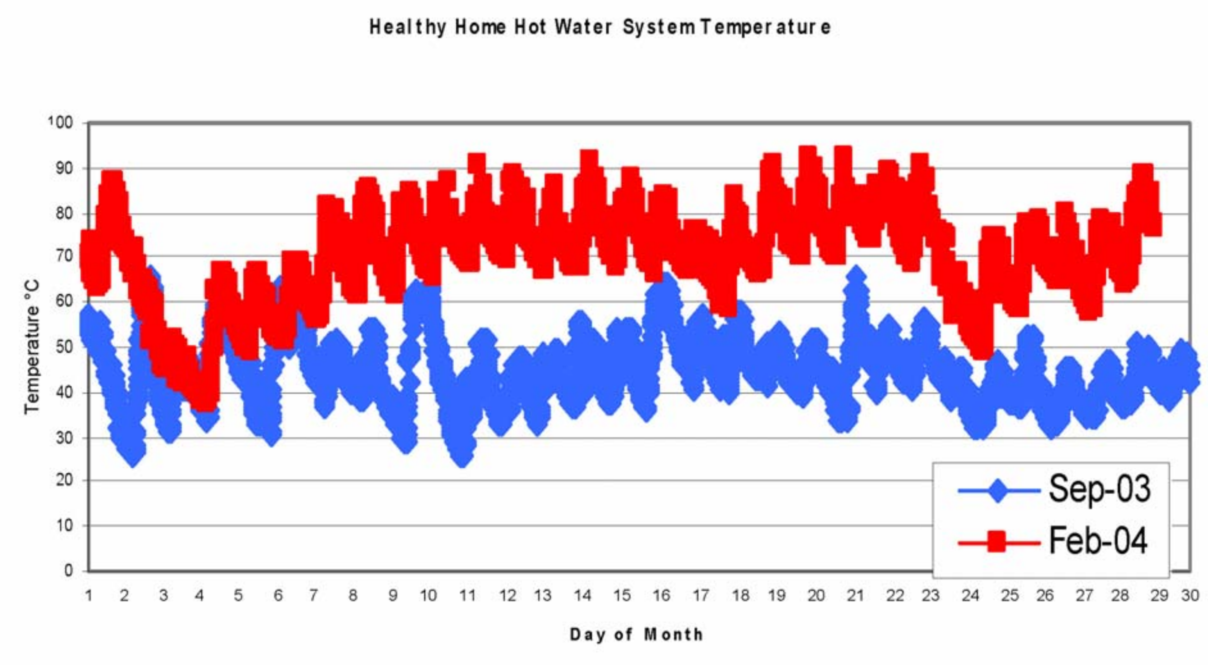


Figure 3.23 Healthy Home water temperature monitoring of hot water from solar hot water system

For both September and February hot water temperature profiles, the cycling of water temperatures between day and night is notable reflecting the difference in ambient air temperatures during day time and night time. Temperature readings show that during February hot water temperature is generally above 60°C even when the booster is turned off. This temperature profile (above 60°C), even though the booster heater was not employed, assures that legionellae in stored hot water is destroyed.

In contrast, during the cooler month of September, hot water temperatures are predominantly in the range 30°C – 60°C. Whilst hot water temperatures during September are on occasions in a temperature range that support *Legionella* growth for extended periods (hours), water is intermittently heated above 50°C where measurable inactivation of legionellae begins (WHO 2002). It is likely therefore, that even if *Legionella* proliferation occurs, subsequent destruction of *Legionella* will occur when water temperature cycles to the higher temperatures, generally during the daytime (this is premised upon their being a sufficient time at temperatures above 50°C to assure bacterial destruction). Presumably hot water temperatures for June, July and August produced stored hot water in a slightly lesser temperature range than for September.

The temperature monitoring data for solar heated hot water in the Healthy Home project highlights that it is possible in some localities, depending upon the ambient temperature and solar intensity to create stored hot water temperatures favourable to *Legionella* growth. The motivations for not employing a booster temperature heater for solar heated water will predominantly include energy saving. The likelihood that the booster heater will be turned off for the whole year however will be dependent upon whether hot water temperatures above at least 35°C can be consistently achieved. Temperatures below this level would probably be regarded by the householder as being ‘too cold for comfort’. At temperatures below 35°C most householders would choose to use a booster heater. However, this does not mean that householders with an ‘energy-saving’ mindset would universally choose to heat stored water to 60°C prior to tempering hot water back to 45-55°C at the point of use.

In relation to the use of rain water tank supply for domestic hot water systems and the risk of legionellosis, current Australian regulations relating to hot water storage temperature (provided that they are followed) are regarded as an effective intervention measure for the control of *Legionella* bacteria irrespective of the source of water for domestic use. Hence, an increased prevalence of *Legionella* bacteria in rainwater tank supplies, as compared with conventional drinking water supplies, gains relevance especially where hot water temperatures are inadequate to control risks. Additional research efforts to ascertain the prevalence of *Legionella* in domestic rain water tanks assume highest priority in those circumstances where changes to hot water storage temperature regulations, such as those motivated by energy saving initiatives, are contemplated and where there is demonstrated widespread non-compliance with current hot water storage temperature regulations.

4 Overall Discussion, Conclusions and Recommendations

4.1 Introduction

This chapter brings together information gained from each of the described studies in previous chapters. In this chapter study findings are discussed and overall conclusions are drawn. This chapter also summarises outstanding information required to answer water and health industry questions that will lead them to develop appropriate policy for rainwater tank use that ensures public health protection. Recommendations are made about how to best fill information gaps. Recommendations made take account of available data and the methodology employed to date in the conduct of rainwater tank water quality studies.

4.2 Microbiological water quality

4.2.1 Overall discussion

Contemplated expanded rainwater use in Australia

The utilisation of roof collected rainwater to supplement conventional drinking water supplies is currently advocated as a means to conserve existing urban drinking water supplies in Australia.

The use of rainwater for garden irrigation and toilet flushing is universally endorsed by health authorities throughout Australia, but this is not the case for use for household hot water systems and for delivery to indoor household taps (e.g. bathroom and laundry).

Whilst use of rainwater for garden irrigation and toilet flushing may lead to significant water savings they are also the same end uses for which recycled water might be employed, hence it is important to explore other end uses for rainwater, such as household hot water and indoor laundry and bathroom tap supply. This is particularly important in integrated urban housing developments incorporating both recycled water schemes and rainwater tanks.

Contemplation of the use of rainwater for expanded purposes in the urban context represents a paradigm shift to current practices and potential health concerns. The delivery of rainwater tank water into the household may result in deliberate or inadvertent consumption of (hot and cold) rainwater tank water (e.g. for drinking, during showering, teeth cleaning, bathing) despite advice to the contrary being given or associated with cross contamination of the conventional drinking water supply with the rainwater tank supply. In the absence of health effects data pertinent to the Australian urban context decisions are being made that potentially result in a diminishment of water savings that might otherwise be achieved and which impact significantly on attainment of water sustainability targets.

Epidemiological and Quantitative Microbial Risk Assessment (QMRA) methodologies may both be employed to obtain requisite health information. Each methodology requires as its basis information relating to household exposure to micro-organisms in rainwater tank water. There is limited available data from rain tank water quality studies of direct relevance to the urban Australian context that may be employed for epidemiological and QMRA purposes.

Thus, in order for the water industry to proceed with measures to conserve conventional drinking water supplies through the expanded use of rainwater tank supplies in urban areas, where a potable supply exists, there is a hierarchy of questions relating to health risk that need to be answered. These questions include:

- Is the health risk associated with untreated rainwater tank water consumption greater than for conventional reticulated drinking water?
- Is the health risk associated with untreated rainwater tank water use for hot water greater than for conventional reticulated drinking water?
- If the health risk of rainwater tank water for various end uses is higher than for conventional reticulated drinking water, is the level of risk for various end uses still within an acceptable risk?

4.2.2 Health risk associated with consumption of rainwater tank water

Microbiological hazards of concern in relation to drinking water provision are the enteric pathogens. Of the projects discussed in this report, both the National survey and the YVW/CERES project included monitoring specifically for some enteric pathogens. Enteric pathogens monitored for included the bacterial pathogens, *Campylobacter* and *Salmonella*. Monitoring for opportunistic pathogen *Aeromonas* was also performed, although the basis for monitoring was as a 'trophic' indicator, not as an indicator of health risk. Both studies also included monitoring for a range of faecal indicator bacteria including *E. coli*, total coliforms, enterococci, *Clostridium perfringens*. No monitoring for protozoan pathogens, *Cryptosporidium* or *Giardia* was performed in any of the described studies.

E. coli results

E. coli results provide some indication of the relative presence of bacterial pathogens that may present a health risk in rainwater tank water as compared with conventional tap water supplies. Prevalence rates recorded for *E. coli* in rainwater tank water samples (National survey = 57%, BCC = 22%, CERES = 100%) are significantly higher than for reticulated waters in urban Australia. Of note is that prevalence rates of *E. coli* are lower for BCC tanks but these tanks are topped up with disinfected reticulated water and are not 'stand alone' tanks. In public drinking water supplies, an absence of *E. coli* in water at the consumers tap is entrenched in regulatory requirements and is used as a measure of the effectiveness of water treatment and other operational practices in removing faecal bacteria. As animals, including birds can transmit pathogens infective for humans, the presence of *E. coli* can never be ignored because the presumptions remain that water has been faecally contaminated (WHO, 1993). On this basis, *E. coli* prevalence data for rainwater tanks supports the current consensus position of Australian health authorities that in situations where a disinfected reticulated water supply is available, such a supply is preferable for potable (drinking) use as the disinfected supply will have more reliable microbiological quality than a rainwater tank supply.

Enteric pathogen results

Analysis for *Campylobacter* and *Salmonella* was performed in both the National survey and in the YVW Ceres study. The number of tanks tested overall in the National study was 35 tanks (total of 67 samples) and in the YVW/CERES trial was 2 tanks (total 14 samples). Neither *Salmonella* nor *Campylobacter* were detected in samples analysed for the YVW/CERES study.

In the National survey *Campylobacter* and *Salmonella* were detected in 3% (N=35) and 6% (N=35) of surveyed rainwater tank waters respectively. On each occasion these bacteria were detected, *E.coli* bacteria were also present. The presence of *Salmonella* and *Campylobacter* in rainwater tank water supports their relevance as plausible causes of disease outbreaks associated with consumption of untreated rainwater tank water. However, whether isolated micro-organisms were infective to man and/or in sufficient numbers to cause infection is unknown. *Salmonella* bacteria detected in two rainwater tank samples were not enumerated nor speciated. Enumeration of *Campylobacter* (detected in one rainwater tank sample) was performed with 43 organisms per Litre recorded but no speciation was performed.

4.2.3 Health risk associated with use of rainwater for hot water supply

Microbiological hazards of concern in relation to hot water supply provision are those bacteria that are able to survive and /or grow in hot water conditions. When considering inhalation and dermal exposure, candidate micro-organisms that may be of potential health significance and which can proliferate at elevated (hot water) temperatures include *Legionella and Mycobacteria*. There is a potential risk of lung infection from *Legionella* and *Mycobacteria* if these organisms proliferate in a warm water environment and aerosol droplets of respirable size are generated. These organisms are sometimes detected in conventional drinking water supplies and are not considered a significant health risk for immuno-competent people.

However, there is little data regarding the prevalence of *Legionella* and *Mycobacteria* in rainwater tanks in an Australian urban context and it is unknown whether the prevalence of these micro-organisms is significantly greater than for conventional drinking water supplies. Additionally there is limited data relating to the prevalence of these organisms in conventional drinking water supplies.

Legionella rainwater monitoring data

Monitoring for *Legionella* was performed in the National survey and in the YVW/CERES study.

Legionella species were detected in eight out of thirty five (23%) rainwater tanks and 10 out of 67 (15%) of samples in the National survey. Overall, out of a total of 67 samples analysed for *Legionella,* a detection limit of <10orgs/mL was applicable to the analysis of 18 samples and a detection limit of <100orgs/L or <0.1/mL was applicable to the analysis of 49 samples. On no occasions the less sensitive detection was applied were *Legionella* species detected. The range of *Legionella* species in positive samples using the more sensitive detection method ranged from 100 – 840,000 orgs/L. (equivalent to 0.1 - 840 orgs/mL). *Legionella pneumophila* (serogroup 1 and 2-14) bacteria were not detected in any rainwater tank samples at either of the two detection limits employed. For the YVW/CERES study, no *Legionella* bacteria were detected in the rainwater tank at the Café on any of the 10 monitoring occasions at the level of method detection (<10 organisms/mL for the period 5/12/03 -3/9/04 and <100/L for Jan 2005 onwards (1 set of results to date)). No *Legionella* bacteria were detected at the Ecohouse on the 2 monitoring occasions during the period 5/12/03 - 3/9/04 nor for the monitoring of 20/1/05.. Of note however is the two detection limits were used in the study for the analysis of samples for *Legionella*.

A potential increase in the risk of legionellosis associated with rainwater tank supplies over conventional drinking water supplies cannot be assumed based on these results for a number of reasons. Firstly, the prevalence of *Legionella* species in Australian conventional drinking water supplies using a similar detection methodology as in this study is largely unknown. Secondly, detected *Legionella* bacteria were not speciated as part of the National survey and YVW/CERES studies and *Legionella* prevalence data for rainwater tank supplies is scant.

In relation to the use of rain water tank supply for domestic hot water systems supply and the risk of legionellosis, current Australian regulations relating to hot water storage temperature (provided that they are followed) are an effective intervention measure for the control of *Legionella* bacteria irrespective of the source of water for domestic use. Hence, an increased prevalence of *Legionella* bacteria in rainwater tank supplies, as compared with conventional drinking water supplies, only gains relevance where changes are contemplated to regulations pertaining to domestic hot water system operation. Research efforts to ascertain the prevalence of *Legionella* in domestic rain water tank are therefore only required to quantify the risk of legionellosis in the absence of compliance with current regulations or where changes to hot water storage temperature regulations, such as those motivated by energy saving initiatives are contemplated.

Stored hot water temperatures

Some temperature monitoring of hot water was performed as part of the BCC study, YVW/CERES study and the Brisbane Healthy Home project. Two of these studies (Brisbane City Council study, YVW/CERES study) hot water heater temperature settings were 60^oC in compliance with AS 3500 (National Plumbing and Drainage Code). For the YVW/CERES study where hot water temperatures lower than expected were initially recorded at the point of hot water delivery, investigation showed that the set point of the hot water heater was less than 60^oC. The temperature setting was immediately adjusted to 60^oC for the remainder of the monitoring period.

Results for hot water for indicator bacteria where monitored (BCC, YVW/CERES) show that where hot water is heated to 60^oC that the removal / inactivation of faecal indicator bacteria will ensue. Likewise, it can be assumed that micro-organisms with a similar thermal resistance profile to indicator bacteria (e.g. *Salmonella*, *Campylobacter* and *Aeromonas*) are also inactivated under these conditions. Results for Brisbane City Council study showed that where hot water temperatures at the point of delivery of hot water were less than 48^oC that indicator bacteria (total coliforms) were detected.

The Healthy Home study provides information regarding the temperature profile of stored hot water where a temperature booster to 60°C is *not* employed. Where a temperature booster is set at 60°C, this means that solar heated hot water is stored at 60°C continuously irrespective of season. Where a temperature booster is turned off, different temperature profiles of stored hot water arise depending upon season. Results for the Brisbane Healthy Home project show that during February hot water temperature is generally above 60°C even when the booster is turned off. In contrast, during the cooler month of September, hot water temperatures are predominantly in the range 30°C – 60°C. Of note for both September and February hot water temperature profiles, is the cycling of water temperatures between day and night reflecting the difference in ambient air temperatures during day time and night time. Whilst hot water temperatures during September are on occasions in a temperature range that supports legionellae growth for prolonged periods, water is intermittently heated above 50°C where measurable inactivation of legionellae begins (WHO 2002).

It is important where changes in the stored hot water temperature regulations are contemplated that they are thoroughly investigated to ensure that sufficient time temperature combinations exist for the inactivation of *Legionella* bacteria. This is important in the context of suggestions that householders turn off boosters of solar hot water systems so as to reduce electricity or gas usage. Thermal inactivation data is available for *Legionella* bacteria in the literature, although it must be acknowledged that temperature resistance of *Legionella* bacteria may vary with species. Nonetheless, it is possible that once temperature profiles of stored solar heated hot water at various localities under various hot water operating protocols (eg booster off always, booster off overnight etc) are obtained that modelling may be performed to ascertain the likelihood of the presence of *Legionella* bacteria in supplied hot water based on available data.

4.2.4 Overall conclusions

This section presents overall conclusions that can be derived from the findings of described studies. In addition, conclusions are made relating to the way in which collected data informs health risk determinations and water industry needs and whether study objectives, as defined in Chapter 1, were met.

Unresolved information

Taking into account rainwater studies described in this report and elsewhere in the scientific literature, the following outstanding information is required to address current health and water industry concerns relating to rainwater tank (and conventional reticulated) water:

- A measure of the health risk associated with drinking untreated rainwater and the inadvertent consumption of untreated rainwater during teeth cleaning, showering etc as it compares with the risk associated with the use of conventional reticulated water for the same purpose. This information is currently not available.

- Information about household practices relating to the operation of solar hot water booster units and the manipulation of temperature settings. Where changes to hot water storage temperatures and hot water unit operation are contemplated as energy saving measures, it is important that the adequacy of the selected temperature time combination to inactivate all micro-organisms of health concern is verified.

- Research is required to verify that the range of domestic hot water system heating regimes, including instantaneous and solar systems, operated according to current domestic hot water storage regulations result in enteric pathogen inactivation.

Conclusions based on described water quality studies

- Results for rainwater tank water quality studies show that prevalence rates for *E. coli* in urban rainwater tank water are significantly higher than for disinfected reticulated waters in urban Australia.

- For the majority of rainwater tanks where *E. coli* were not detected, enterococci bacteria were present indicating remote, if not recent, faecal contamination of tank waters.

- Bacterial pathogens, *Campylobacter* and *Salmonella* were detected in some rainwater tank waters confirming their relevance as a plausible cause of disease outbreaks associated with consumption of rainwater tank water. No speciation of *Campylobacter* or *Salmonella* was performed to ascertain whether detected organisms were pathogenic for man. Also, enumeration of detected bacteria was only performed for *Campylobacter*.

- General high numbers of heterotrophic plate count bacteria are potentially associated with one or more factors including low turnover of water in the tank, high input of vegetative matter on which bacteria are able to grow and multiply and build up of sediment in the tank also supplying nutrients for bacterial growth.

- Rainwater tank results show that water from rainwater tanks is more variable in microbial quality compared with conventional tap water supplies.

- The detection of *Clostridium perfringens* and *Aeromonas* bacteria in rainwater tank water is in accord with the ubiquity of these organisms in the environment (soil, vegetation etc). In addition, *Aeromonas* is nutritionally versatile and bacterial growth may occur associated with nutrient loading of the rainwater tank water.

- A possible reason for the low overall prevalence rate of *E. coli* in rainwater tank water at Mutitjulu is the low frequency of access by birds and small animals to the roof catchments. In addition, even when faecal matter is deposited on the roof; die-off of faecal bacteria on the roof catchment may occur as a consequence of UV irradiation and other mechanisms (heat, desiccation etc), consistent with harsh climatic conditions. Furthermore, the opportunity for bacterial die-off occurring on the roof catchment is enhanced when the period between rainfall events is extended. High water temperatures may also result in the rapid die-off of *E. coli* bacteria in the tank water itself.

Conclusions relating to study objectives, industry needs and health risk determinations

- The impact of various rainwater tank characteristics on microbiological water quality cannot be elucidated from National survey data. This is due to the variable characteristics of individual rainwater tanks such that when rainwater tanks (total 35 tanks) are segregated according to their characteristics (materials, volume, household size etc), groups sizes are too low to allow conclusions to be drawn.

- The ability to interpret longitudinal data for variations in microbiological water quality is not possible using National survey data as each rainwater tank was surveyed on a maximum of 2 occasions. For this objective to be satisfied, intensive water quality monitoring of water in individual rainwater tanks would be required to elucidate patterns in microbiological water quality variations. Interpretation of longitudinal data would also require that detailed rainfall, observational (eg birdlife etc on roof catchment) and water usage data be concurrently collected.

- The ability to extrapolate microbiological data obtained for rainwater tank water in the Brisbane City Council study to other rainwater tanks is somewhat limited. Nonetheless, this data is valuable as the Brisbane City Council rainwater tank configuration is being contemplated elsewhere. Results indicate that where a water supply of good microbiological quality (and one where residual chlorine is present) is used to top-up rainwater tank water, an improvement of the microbiological quality of rainwater tank water, as measured using indicator bacteria, is likely to ensue.

- Whilst results of water quality studies support the position that disinfected drinking water presents a lower health risk for drinking as compared with rainwater tank water, there is no available data to enable the risk to be measured and for it to be ascertained whether the health risk from rainwater tank consumption is nevertheless acceptable.

- Based on the limitations and cost of QMRA and epidemiological studies the superior approach is to conduct an epidemiological study to which is appended water quality investigations. This is because a targeted health (epidemiological) study answers health questions directly, the methodology is robust and study duration of one year potentially allows needed longitudinal data to be collected for a large number of rainwater tanks over this period for subsidiary purposes (e.g. effect of rainwater tank maintenance on water quality). The disadvantage associated with using QMRA alone to obtain needed health information is the relatively high cost of obtaining necessary data (enumeration and speciation of a range of pathogens included), the lack of a direct health measure and the absence of an appropriate comparative measure of the health risk associated with the use of conventional tap water for the same purposes.

4.2.5 Overall recommendations for further research

This section presents recommendations as to how future studies might be performed to provide the water and health industry with relevant information that will lead them to develop appropriate policy for rainwater tank use that will ensure public health protection.

It is recommended that:

1. Further research is undertaken to supplement currently available data relating to the presence of enteric pathogens in roof collected rainwater. Monitoring of rainwater tank water for enteric pathogens as part of the NH&MRC funded randomised double blinded intervention study conducted in 2007/2008 in Adelaide provides an opportunity for such supplementation of existing datasets in parallel with the monitoring of the health status of householders using water for drinking purposes.

2. Information about the impact of design, material, operational and maintenance factors in existing rainwater tanks on microbiological quality is obtained. Possible ways in which this information might be obtained economically include appending rainwater tank water quality surveys to health studies where large enough numbers of rainwater tanks are available to be surveyed on multiple occasions. The NH&MRC funded randomised double blinded intervention study being conducted in 2007/2008 provides such an opportunity as relatively high numbers of tanks (300) will be fully characterised in terms of physical and design characteristics.

3. In the absence of opportunities to conduct water quality monitoring as part of other studies, experimental studies using indicator micro organisms fit for purpose potentially provide the best and most economical means to investigate strategies that minimise microbial contamination of roof collected rainwater. This is because such studies allow levels of contamination and rainfall to be manipulated to reflect worst-case scenarios and rainwater tank variables can be controlled.

4. Research is undertaken to verify that the range of domestic hot water system heating regimes, including instantaneous and solar systems, operated according to current domestic hot water storage regulations result in enteric pathogen inactivation.

Research efforts to ascertain the prevalence of *Legionella* in domestic rain water tank are not recommended at this stage. Research efforts in this area are only required to quantify the risk of legionellosis in the absence of compliance with current hot water storage temperature regulations or where changes to hot water storage temperature regulations, such as those motivated by energy saving initiatives, are contemplated.

Research into the prevalence of *Mycobacterium* species in rainwater tank water is likewise not recommended at this stage premised on the maintenance of current hot water storage regulations and associated with the relative cost and availability of analytical tests for *Mycobacteria* species of interest in rainwater.

4.3 Chemical water quality

The exposure pathways for chemicals in rainwater tanks are essentially the same as for microbes and the same context of rainwater use in Australian households applies to chemical contaminants. As such the 2004 ADWG are used as a benchmark to examine the suitability of different end uses and any health risk if rainwater is drunk.

Overall the chemical water quality shows that rainwater in Australia is soft water with low total dissolved solids or salts which is in agreement with studies in other countries (Hontoria *et al.* 2003). Water from tanks in urban Australia is generally slightly acidic but cannot be regarded as acid rain with the exception of one sample from Adelaide with a pH of 3. Acid rain is where the pH is lower than the acidity of pure water in equilibrium with CO_2 in the atmosphere, which is a pH of <5.6 (Avila and Alarcon, 1999; Hu *et al.* 2003). The lack of acid tank water is an indication that industrial and motor vehicle emissions are not significant inputs to rainwater in Australia. However, storage in tanks may neutralise some acidity through reaction with dust and organic matter also collected in the tank. The variability of tank water pH is much greater than municipal supply as shown by the Brisbane 30 tank study. This high variation in water quality between tanks and over time makes it more difficult for assessment of the risk with different end uses of tank water.

The soft and sometimes acidic nature of the rainwater is likely to cause corrosion of pipes and this is suggested from the results of the Brisbane and Melbourne data, where tank water passing through the hot water system had higher levels of copper and greater incidence of detection for lead and nickel. The generally soft water may also be a risk for electrical hot water systems that have a sacrificial anode designed for hard water such as in Brisbane municipal supply. This could lead to an overactive anode and production of explosive hydrogen gas.

The addition of limestone ($CaCO_3$) chips or powder to tanks may be a preventative measure to neutralise acidity and increase the calcium content and hardness of tank water as calcium compounds are known to be a major buffering compound in rainwater (Conlan and Longhurst, 1993). It is recommended that the effectiveness of this measure in decreasing the corrosiveness and softness of tank water is validated in real tanks before it recommended in practice.

When examining other chemical contaminants on an individual basis in the majority of situations the chemical water quality from rainwater tanks is unlikely to cause any chemical related health problems if it is drunk. However, this is not always so in some tanks or at certain times. Some hydrocarbons, phthalates and herbicides have been detected in some samples indicating that they are present on some occasions. For the PAHS, excluding a couple of samples in Melbourne, they were not measured with significant sensitivity to comment on their presence affecting health. Heavy metals are another class of compounds that is of concern in some tanks.

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7 Appendices

Appendix 1 REQUIREMENTS & INSTRUCTIONS - NATIONAL SURVEY OF RAINWATER TANKS

References:

- **Sampling Collection and Handling Procedure**
- **Customer Information Form.**

General requirements and instructions are described below:

- Sampling from rainwater tanks shall be undertaken twice, once around June / July 2004 and then again around November / December 2004.
- The sampling shall only occur from above ground rainwater tanks.
- The chosen location of tanks should be in a situation whereby chemical deposition on roofs is possible, i.e., near freeways, under flight paths, etc.
- Sampling is to occur during or after (say the next day) a rainfall event of greater than 5mm in magnitude. This will hopefully ensure a suitable quantity of rainwater has entered the tank particularly as many tanks may be fitted with first flush devices.
- About a week of dry weather (or more) should occur before the chosen rainfall event of greater than 5mm in magnitude.
- Where possible, preference shall be given to sampling from tanks that do not have potable water top-up facilities. This is to avoid the possibility of chlorinated water affecting the results. Where it is not possible to avoid sampling from tanks that do have potable water top-up facilities, care should be taken that a sufficient volume of water is in the tank (say over half full).
- Water shall be drawn from the outlet tap of the tank and not from grab sampling inside the tank.
- Sites and numbers:
    - Adelaide (6) by SA Water.
    - Broken Hill (6) by NSW Health.
    - Melbourne (2) by Yarra Valley Water at CERES.
    - Sydney (6) by Sydney Water.
    - Wollongong (6) by Sydney Water.
    - Brisbane (6) - by Brisbane City Council.
    - Canberra (5) by ACTEW.

APPENDIX 2 LIST OF ANALYTES

CHEMISTRY	**TRACE METALS**	**VOLATILE ORGANICS**
pH	Digestion*	Dibromochloromethane
Conductivity	Total Aluminium	Ethyl benzene
Turbidity	Total Cadmium	o-Xylene
TOC	Total Calcium	Toluene
DOC	Total Chromium	(m+p)-Xylenes
Hardness	Total Cobalt	Benzene
True Colour	Total Copper	Bromodichloromethane
TDS	Total Iron	Bromoform
Nitrate	Total Lead	Chloroform
Sulphate	Total Lithium	
Temperature	Total Magnesium	**PHENOLICS**
	Total Manganese	2,3,4,6-tetrachlorophenol
HYDROCARBONS	Total Nickel	2,4,5-trichlorophenol
Preparation*	Total Potassium	2,4,6-trichlorophenol
TPH C6-C9	Total Sodium	2,4-dichlorophenol
TPH C10-C14	Total Strontium	2,4-dimethylphenol
TPH C15-C28	Total Zinc	2,6-dichlorophenol
TPH C29-C36		2,-chlorophenol
	ORGANOCHLORINE PESTICIDES	2-methylphenol
PAH	4,4-DDD	3-methylphenol
Total Detectable TDPAH	4,4-DDE	4-chloro-3-methylphenol
Acenapthene	4,4-DDT	4-methylphenol
Anthracene	Aldrin	Pentachlorophenol
Benzo(a)anthracene	alpha-BHC	Phenol
Benzo(a)pyrene	alpha-Chlordane	
Benzo(b)fluoranthene	alpha-Endosulfan	
Benzo(e)pyrene	beta-BHC	
Benzo(ghi)perylene	beta-Endosulfan	
Benzo(k)fluoranthene	delta-BHC	
Chrysene	Dieldrin	
Dibenzo(a,h)anthracene	Endosulfan Sulphate	
Fluoranthene	Endrin	
Fluorene	gamma-Chlordane	
Indeno(1,2,3-cd)pyrene	Heptachlor	
Napthalene	Heptachlor epoxide	
Phenanthrene	Hexachlorobenzene	
Pyrene	Lindane (gamma-BHC)	
Acenaphthylene	Methoxychlor	
	Total Chlordane	

PHTHALATES	**PHENOXY HERBICIDES**	**BIOLOGICAL**
Dimethyl phthalate	2,4,5-T	*E.coli*
Diethylphthalate	2,4-D	Enterococci
Dibutylphthalate	2,4-DB	*Salmonella*
Butylbenzylphthalate	3,5-Dichlorobenzoic Acid	*Campylobacter*
Bis(2-ethylhexyl)Adipate	Bentazon	*Legionella spp. and also Legionella pneumophila*
Bis(2-ethylhexyl)Phthalate	Choramben	*Aeromanus*
Di-n-Octylphthalate	Chlothal	*Clostridium perfringens*
	Clopyralid	Thermotolerant Coliforms
ORGANO-PHOSPHORUS PESTICIDES	Dicamba	Total Coliforms
Demeton-S-Methyl	Dichlorprop	HPC
Diazinon	Dinoseb	
Dichlorvos	MCPA	
Dimethoate	Mecoprop	
Disulfoton	Pentachlorphenol	
E.P.N.	Picloram	
Ethoprop	Silvex (2,4,5-TP)	
Ethyl azinphos	Triclopyr	
Ethyl chlorpyrifos		
Fenitrothion		
Fensulfothion		
Fenthion		
Fonofos		
Isazophos		
Malathion		
Methyl azinphos		
Methyl chlorpyrifos		
Mevinphos		
Parathion		
Phospholan		
Trithion		

APPENDIX 3 NATIONAL SURVEY ANALYTE AMENDMENT LIST (1 to 6)

25 JUNE 2004

Amendment 1: Incorrect Analyte Name

Benzenebuthylphthalate is incorrectly named and should be **butylbenzylphthalate** according to conventional nomenclature.

Amendment 2: Deletion of VOC

VOC has been identified as one of the parameters to be tested as part of the National survey. Several problems have emerged with this parameter:

- VOC can be interpreted as both Volatile Organic Compounds and Volatile Organic Carbon (it was meant to stand for Volatile Organic Carbon);
- The method to determine Volatile Organic Carbon is varied across project participants.

Additionally we have found that most labs in Sydney do not perform the Volatile Organic Carbon test. We have been advised that many examinations produce gross errors and the usefulness of the figure is questionable. Thus it is recommended that the measurement of Volatile Organic Carbon be dropped from the list of parameters.

Amendment 3: Analysis Volumes for Certain Microbiological Analyses

Analysis of ONE LITRE volumes for the analysis of each of *Campylobacter, Salmonella* and *Legionella* is required, i.e. for the 3 tests, 3 Litres are required.

The rationale for this instruction is that the numbers of bacterial pathogens in rainwater tank water are expected to be low. Consequently it is important to analyse an appropriate sample volume. ONE LITRE volumes are considered appropriate.

Amendment 4: Recommended Methods and a Concentration Step for Certain Microbiological Analyses

Use of the Australian Standard Method is recommended for the determination of microbial pathogens.

Concentration of *Salmonella* and *Campylobacter*

Both *Salmonella* (AS4276.14: 1995) and *Campylobacter* (AS/NZS 4276.19:2001) methods include a concentration step as part of the Standard. Thus, concentration methods, as specified in the Standards, should be employed for the concentration of the collected 1 Litre samples for these microorganisms.

Concentration of Legionella A concentration step is not specified in the *Legionella* method (AS/NZS 3896:1998) but reference is made to the need to perform such a step for particular sample types. In the Preface to the *Legionella* method p.2 it states 'If low levels of *Legionella* spp are anticipated in a test, water concentration methods may be required, for example, for cold-treated potable waters'. In addition, it states that 'Because of the diverse nature of environmental samples and the different methods used for their initial treatment before cultural examination, it has not been possible to include such preparative treatments in this Standard'.

In the absence of the AS/NZS 3896:1998 detailing a concentration method, it is requested that all laboratories perform the following concentration method prior to the execution of the AS/NZS 3896 method as detailed in Appendix A of the standard.

Step 1: Filter the entire 1 Litre volume through a 0.2 micron filter membrane. Note that where tank water samples are turbid it may be necessary to use 2 membrane filters with 500mL volumes filtered through each. If the sample is very turbid and it is only possible to filter small volumes through the membrane filter, the total volume filtered through each of the membrane filters should be recorded.

Step 2: Cut up the membrane(s) using sterile scissors (flamed with alcohol) and place in a container with 10mL of sterile distilled water.

Step 3: Vortex for 2 minutes and then proceed as per Appendix A in AS/NZS 3896:1998.

Amendment 5: Preference for *E. coli*

E.coli is to be analysed rather than thermotolerant coliforms. This amendment is included to ensure that all partners at least sample for *E.coli*.

Thermotolerant coliform tests can still be undertaken if you so wish.

Amendment 6: HPC Temperature

HPC tests to be undertaken at 36 plus or minus 1 degrees C. This amendment is included to ensure that all partners at least sample for HPCs at 36 plus or minus 1 degrees C.

HPC tests at other temperatures can still be undertaken if you so wish.