GUIDANCE ON USE OF RAINWATER TANKS

enHEALTH

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The enHealth Council, a subcommittee of the National Public Health Partnership, brings together top Environmental Health officials at the Federal and State/Territory level along with representation from the Australian Institute of Environmental Health, the environment and public health sectors, the Indigenous community and the wider community. The Council has responsibility for providing national leadership, implementation of the National Environmental Health Strategy, forging partnerships with key players, and the development and coordination of advice on environmental health matters at a national level. The advice development process is strongly based on collaboration and consultation. Further information on the enHealth Council can be obtained from their website: http://enhealth.nphp.gov.au/

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PREFACE

This second edition of *Guidance on use of rainwater tanks* has been produced by the enHealth Council to revise the monograph produced in 1998 by its precursor group, the National Environmental Health Forum. The revision was thought timely in response to increased interest in using domestic rainwater tanks in both rural and urban areas. This increased interest has arisen because of widespread drought conditions, predictions of worldwide shortages of fresh water as populations continue to grow, and increased water restrictions. The number of agencies offering incentives for installation of domestic tanks has also increased.

The format of this edition has been changed to ensure consistency with the *Framework for drinking water quality management* incorporated in the new *Australian drinking water guidelines* (in press). The framework advocates implementation of a preventive risk management approach for assuring water quality. While this type of approach was the basis for the first edition, this edition has organised the information in a more systematic manner.

The monograph consolidates the most up-to-date information and advice as a resource for Environmental Health Officers and other professionals, and for those members of the public seeking detailed guidance. Information is provided on the range of potential hazards that can threaten water quality, preventive measures that can be used to prevent these hazards from contaminating rainwater, straightforward monitoring and maintenance activities, and, where necessary, corrective actions.

Collection and storage of rainwater involves relatively simple systems. A reasonably low level of management can ensure provision of good quality water that can be used for a wide range of purposes including drinking, food preparation, bathing, laundry, toilet flushing and garden watering.

The monograph includes information on design and installation as well as the potential contribution of rainwater tanks to improved water conservation.

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EnHealth Council would especially like to thank Dr David Cunliffe for contributing his time and expertise to update this valuable resource. Dr Cunliffe was the author of the original version published under the National Environmental Health Forum.

Sources of information

Rainwater tanks – Information used in preparing this monograph was obtained from a range of published and unpublished reports, as well as from the accumulated experience of health agencies in dealing with rainwater tanks. Copies of unpublished material were very kindly provided by a range of State government agencies, as acknowledged in the bibliography.

Household water use data – Total household usage of water in each State was taken from the *Water account for Australia* (ABS 2000). The proportions of water used for different purposes were taken from a number of sources including the Water Services Association of Australia *Water consumption fact sheet 2001*, the Water Corporation (Western Australia) *Planning for Perth's water needs* and the Water Resources Strategy for the Melbourne Area Committee *Planning for the future of our water resources: Discussion starter* (2001).

1. INTRODUCTION

> Water is a limited natural resource and a public good fundamental for life and health. The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights. (United Nations 2002)

Australia has a generally hot, dry climate and fresh water is a limited and valuable commodity. Over 90 per cent of Australians receive their domestic supply from reticulated mains or town water but there are vast areas with very low population densities with few reticulated supplies (Australian Bureau of Statistics 2001). Living and surviving in these areas depends on the use of local sources of water such as rainwater collected in tanks and groundwater. Even in areas that receive mains water, many households collect rainwater in domestic tanks to augment supplies or provide an alternative and renewable source of water. Widespread water restrictions in 2002–03 involving several capital cities, large urban areas and hundreds of rural centres highlighted the importance of water conservation measures, including use of rainwater tanks. A number of agencies have offered cash rebates to support installation of rainwater tanks.

Collection of rainfall from roof run-off is an ancient practice that dates back over 3000 years. In Australia the use of domestic rainwater tanks is an established and relatively common practice, particularly in rural and remote areas. Between 1994 and 2001, 16 per cent of Australian households used rainwater tanks, with 13 per cent of households using tanks as their main source of drinking water (see Table 1). Use of tanks as the main source of water for gardens (3%) or bathing, showering and washing (6%) is less common.

TABLE 1: DOMESTIC USE OF RAINWATER TANKS IN AUSTRALIA

STATE/TERRITORY	HOUSEHOLDS WITH RAINWATER TANKS (%)	RAINWATER TANK AS MAIN SOURCE OF DRINKING WATER	CAPITAL CITY* HOUSEHOLDS WITH RAINWATER TANKS (%)	NON-CAPITAL CITY HOUSEHOLDS WITH RAINWATER TANKS (%)
NSW	10	8	3	30
Vic.	13	11	3	36
Qld	18	15	5	29
SA	51	36	37	80
WA	11	8	5	30
Tas.	17	14	6	19
NT	3	2	nd	nd
ACT	1	0.2	nd	nd
Total	**16**	**13**	**7**	**34**

Source of data: Australian Bureau of Statistics 1994–2001
* for NSW this includes the Sydney, Newcastle and Wollongong areas
nd = not determined

Not surprisingly, the driest state, South Australia, had the highest rate of usage, with 51 per cent of households (ABS 1994–2001) having a rainwater tank and 36 per cent using them as the main source of drinking water. The Northern Territory (2%) and the ACT (0.2%) recorded relatively low rates of use (see Table 1). Use of rainwater tanks is more common outside capital cities. In the 1994 ABS survey, 34 per cent of households outside the capital cities had a rainwater tank, compared to 7 per cent of city households. In a 1996 South Australian survey, 28 per cent of Adelaide households used rainwater tanks as the primary source of drinking water compared to 82 per cent of households in the rest of the State (Heyworth et al. 1998).

Although there has been some debate about the volumes of water that can be provided from rainwater tanks, tanks can be a significant source of drinking water even in arid regions. The 2001 ABS survey found that 83 per cent of households with rainwater tanks considered the volume of water supplied was sufficient for their needs. The main reason given for not installing a rainwater tank was, cost (38%), followed by lack of time (26%), and lack of room (15%). Only 5 per cent of those who had considered installing a tank had decided not to because of health concerns.

As well as using tanks as a conservation measure, some choose to install them as a means of independently collecting a relatively pure product (at least before collection) and using it without treatment, and in particular, without the addition of chemicals.

The general public perception is that rainwater is safe to drink. In most areas of Australia, the risk of illness arising from consumption is low, providing it is visually clear, has little taste or smell and, importantly, the storage and collection of rainwater is via a well maintained tank and roof catchment system. While the risk from consuming rainwater is low in most areas of Australia, the water from domestic tanks is not as well treated or managed as the major urban water supplies. The microbial quality of water collected in tanks is not as good as the urban supplies. In a limited number of areas, specific industries or very heavy traffic emissions may affect the chemical quality of rainwater.

Rainwater can be used as a source for hot water services, bathing, laundry, toilet flushing, or gardening. These uses represent lower risks to public health than drinking rainwater.

Irrespective of how tank rainwater is used, water quality is dependent on implementing a sensible maintenance program. However, while maintenance requirements are not particularly onerous, in practice most roof catchments and rainwater tanks are poorly maintained. This may reflect the notion that rain is a relatively pure source of water and it may be related to the fact that in many rural areas, the availability of water is a bigger issue than quality.

The aim of this monograph is to consolidate information and advice on rainwater tanks in one document. The monograph presents a description of the issues and provides guidance on managing rainwater collected in domestic tanks in a way that should maximise the quality of water supplied from these tanks. The information on management and water quality is consistent with the general advice provided in the *Australian drinking water guidelines*.

2.

USES OF RAINWATER

Although the most common use of rainwater tanks is to supply drinking water, there has been much debate over the suitability of using household tanks for this purpose. This debate has tended to be focused in the major urban centres where high quality mains water is available. In rural and remote parts of Australia, use of rainwater tanks to supply drinking water has been a long-standing and often essential practice.

The decision about how to use rainwater is a matter of personal choice. In making this decision, it should be recognised that, although the risk of contracting illness from rainwater supplied from well-maintained roof catchments and tanks is low, the quality of water from household tanks is not as consistently high as that provided by well-managed urban water supplies. Microbiological quality is not as reliable as mains water, particularly after rain events. In addition, there are a few areas where impacts from major industrial emissions (for example, Port Pirie, South Australia) mean tank rainwater is not suitable for drinking and food preparation. The impacts on rainwater of very large densities of traffic, and other emissions, in Sydney and Melbourne are yet to be determined.

One option to decrease any potential risk from tank rainwater is to minimise oral exposure by limiting use of the collected water to supplying hot water services, bathing, laundry, toilet flushing or gardening (that is, not for drinking or food preparation).

The water quality requirements for non-potable uses are lower than those for drinking water. Guideline values cited in the *Australian drinking water guidelines* are based on a daily consumption of 2 L of water per day for an adult and 1 L for a child. Consumption or ingestion from showering is generally less than 100 mL per day. Ingestion associated with laundry use, toilet flushing and gardening would be even lower.

Use of rainwater to supply hot water services has attracted increasing interest. From a practical economic view, hot water supplies involve separate plumbing systems, so it is relatively easy to incorporate the use of rainwater in a house for this purpose, with minimal duplication of pipes or fittings.

In hot water systems, risk from rainwater is lowered by a combination of reduced exposure and thermal inactivation of enteric pathogens (microorganisms that cause gastrointestinal illness). Drinking water from hot water services is generally not recommended.

Those who use water directly from domestic hot water services to make beverages such as tea and coffee, should note that additional heating, such as boiling, provides further inactivation of pathogens (see Section 5, Disinfection).

3.

MANAGING RAINWATER QUALITY – AN OUNCE OF PREVENTION

Health and aesthetic hazards for rainwater collected in tanks can be minimised by sensible management procedures. With the possible exceptions of urban traffic emissions in very highly populated centres, and industrial emissions, these hazards are amenable to individual action. Some preventive measures are associated with design and installation, while others are associated with ongoing maintenance. Well-designed systems are low maintenance.

Roof catchments, guttering, piping and rainwater tanks are relatively simple systems. Implementation of a relatively low-key management approach will generally prevent problems occurring, so corrective action to restore water quality will be needed infrequently, if at all.

As discussed in the *Australian drinking water guidelines,* a preventive risk management approach is the most effective way of ensuring safe, high quality drinking water. This applies to all types of water supply, including rainwater collected in domestic tanks. The latest version of the guidelines includes a 'framework for management of drinking water quality'. The framework addresses four general areas, and while each is important for community-based supplies, the area of *system analysis and management* is of prime importance for owners of domestic rainwater tanks. 'System analysis' involves identifying and assessing the hazards that can compromise rainwater quality while 'system management' deals with applying preventive measures to minimise risks to health, supported by monitoring and, where necessary, corrective action. For domestic rainwater tanks, monitoring mainly takes the form of visual inspection. These issues will be discussed in the following sections.

4. IDENTIFYING POTENTIAL HAZARDS AND HEALTH RISKS (SYSTEM ANALYSIS)

Assessment of the health risk of rainwater tanks requires consideration of whether a hazard to human health is present and whether the dose of the hazardous material is sufficient to cause illness. Both the concentration of the hazard and the degree of exposure determine the dose (of hazardous chemicals and pathogenic microorganisms). The most common use of rainwater tanks in Australia is to provide a private source of drinking water to individual households. This use provides the highest level of exposure compared to other domestic and gardening uses. Use of rainwater for purposes other than drinking is discussed in Section 2.

Rainwater tanks are also used as a source of public or community-based drinking water supplies. This type of use requires consideration of broader legislative or duty-of-care requirements and is discussed in Section 11.

Collection and storage of rainwater introduces the potential for chemical, physical and microbial contamination. The most common hazards in water sources obtained from surface catchments worldwide, including roof run-off, are microbial pathogens of faecal origin (enteric pathogens). In most of Australia (exceptions are discussed below) chemical and physical quality of rainwater is relatively easy to maintain, but microbial quality is more difficult to manage. This is supported by investigations of rainwater quality as discussed below.

Rainwater tanks can also represent a health risk by providing breeding sites for mosquitoes.

Microbial hazards

Rainwater collected and stored in domestic tanks will contain a range of microorganisms from one or more sources. While most will be harmless, the safety of rainwater will depend on excluding or minimising the presence of enteric pathogens. Enteric pathogens include types of bacteria, viruses and protozoa. These organisms do not grow or survive indefinitely in water environments and are introduced into drinking water supplies by contamination with faecal material.

Tank rainwater can contain organisms referred to as opportunistic pathogens such as *Aeromonas* spp. and *Pseudomonas aeruginosa*. Except to the severely immunocompromised these organisms are not considered to represent a significant risk through normal uses of drinking water supplies (WHO 2002).

Most domestic rainwater tanks are installed above ground and collect run-off from roofs via guttering. Likely sources of enteric pathogens include:

- faecal material (droppings) deposited by birds, lizards, mice, rats, possums etc.
- dead animals and insects, either in gutters or in the tank itself.

Less commonly, rainwater is collected in underground tanks. If these tanks are not fully sealed or protected against ground run-off, then microorganisms associated with human and animal excreta may also contaminate stored rainwater.

Microbial quality of drinking water is commonly measured by testing for *Escherichia coli* (*E. coli*), or alternatively thermotolerant coliforms (sometimes referred to by the less accurate term faecal coliforms), as indicators of faecal contamination and hence the possible presence of enteric pathogens. In the past, the broader total coliform group has also been used for this purpose. However, this group includes non-pathogenic organisms that can grow in water environments and hence that can be present in the absence of faecal contamination. Accordingly, total coliforms are no longer recognised as being a suitable indicator of faecal contamination or having health significance (*Australian drinking water guidelines*).

Thermotolerant coliforms or *E. coli* have been commonly identified in domestic tanks (Fuller et al. 1981; Dillaha & Zolan 1985; Fujioka & Chin 1987; Haeber & Waller 1987; Wirojanagud 1987; Gee 1993; Edwards 1994; Thurman 1995; Victorian Department of Natural Resources and Environment 1997; Simmons et al. 2001; unpublished results SA Water and Victorian Department of Human Services). This implies that enteric pathogens could often be present in rainwater tanks. However, when surveys have included testing for specific pathogens, detection has not been common.

In Australia, *Campylobacter* was identified in six of 47 tanks in one survey (Victorian Department of Human Services unpublished results), whereas other pathogens, such as *Salmonella, Shigella, Cryptosporidium* and *Giardia*, were not detected in a number of surveys of domestic rainwater tanks (Fuller et al. 1981; Thurman 1995; Victorian Department of Natural Resources and Environment 1997; Victorian Department of Human Services unpublished results).

In New Zealand, *Campylobacter* was identified in nine of 24 tanks, but the maximum concentrations were less than one per 100 mL and it was concluded that the risk of illness from drinking this water was low (Savill et al. 2001). A second New Zealand survey found faecal coliforms in 70 of 125 rainwater tanks but *Salmonella* was only detected in one tank. *Cryptosporidium* oocysts of unknown species were detected in two of 50 tanks that contained at least 30 faecal coliforms or 60 enterococci per 100 mL (Simmons et al. 2001). *Campylobacter* or *Giardia* was not detected in any tanks. Similarly Wirojanagud (1987) reported the detection of faecal coliforms in 43 of 156 samples from rainwater tanks in Thailand, but *Salmonella* was only detected in one sample and *Shigella* in none. An exception to this trend was the detection of *Cryptosporidium* and *Giardia* in 400 L samples, collected from a large number of rainwater cisterns in the Virgin Islands, where installation of rainwater storage is compulsory due to a lack of fresh water resources (Crabtree et al. 1996). The health significance of this finding has not been established.

Illness and rainwater tanks

The relatively frequent detection of faecal indicator bacteria is not surprising, given that roof catchments and guttering are subject to contamination by bird and small animal droppings. However, despite the prevalence of indicator organisms, reports of illness associated with rainwater tanks are relatively infrequent. Although traditional under-reporting of gastrointestinal illness will have contributed to a lack of evidence, epidemiological investigations undertaken in South Australia also failed to identify any link (Heyworth et al. 1999; Heyworth 2001).

The South Australian investigations compared rates of gastrointestinal illness in children who drank rainwater collected in domestic tanks, compared to those who drank filtered and disinfected mains water that was fully compliant with the *Australian drinking water guidelines*. Overall, the investigations found no measurable increase in illness associated with drinking rainwater. In the first part of the investigation, a questionnaire was administered to parents of about 9500 children undertaking a general health check before enrolling at school for the first time. There was a slightly higher, but non-significant, incidence of gastrointestinal illness reported for rural children who drank rainwater rather than mains water (Heyworth et al. 1999). There was no difference in rates of illness between children drinking rainwater or mains water in urban areas.

The second part of the investigation expanded on the results for the rural children through use of a diary study with parents of about 1000 rural children. The results were reversed and the study found a small but significant decrease in illness associated with consumption of rainwater compared to mains water (Heyworth 2001). The investigations included questions about rainwater tank maintenance. As found in most surveys, maintenance was generally poor.

There have been a few reports of illness associated with *Campylobacter* and *Salmonella* in rainwater tanks. In four of these reports the contaminating organisms were detected in both those infected and their rainwater sources (Koplan et al. 1978; Brodribb et al. 1995; Simmons & Smith 1997; Taylor et al. 2000). Brodribb et al. (1995) reported an investigation into recurrent infections by *Campylobacter fetus,* of an elderly immunocompromised woman where the organism was also isolated from the patient's rainwater tank, which served as her sole source of drinking water. No further infections occurred after the patient started boiling the tank water before consumption. It was postulated that an outbreak of 23 cases of campylobacteriosis at a Queensland island resort was probably associated with contamination of rainwater tanks, even though *Campylobacter* was not isolated from rainwater samples (Merritt et al. 1999). A study of risk factors for campylobacteriosis in New Zealand associated consumption of rainwater as a source of increased risk in a small number of cases (23 cases, 11 controls; odds ratio 2.2) (Eberhart-Phillips et al. 1997).

An investigation of an outbreak of *Salmonella* infections in a church group in Trinidad, Jamaica led to detection of the organism in rainwater samples and in food prepared using the rainwater (Koplan et al. 1978). It was reported that the roof catchment was covered with dried and fresh bird droppings. Similarly, *Salmonella* was isolated from a rainwater tank used by a family of four in New Zealand that had suffered from recurrent infections by the same organism (Simmons & Smith 1997). In an investigation of 28 cases of gastroenteritis among 200 workers at a construction site in Queensland, *Salmonella* Saintpaul was isolated from both cases and rainwater samples (Taylor et al. 2000). Animal access was suggested as being the source of contamination with several live frogs being found in one of the suspect tanks.

An undergound rainwater tank was associated with the only drinking waterborne outbreak of cryptosporidiosis/giardiasis recorded in Australia to date (Lester 1992). Eighty-nine people supplied with drinking water from the tank became ill. Investigations revealed the tank had been contaminated by an overflow from a septic tank.

One explanation for the apparent disparity in frequency of faecal contamination and the prevalence of illness could be the likely source of contamination. For most rainwater tanks, particularly those installed above-ground, faecal contamination is limited to small animals and birds. While faecal contamination from these sources can include enteric pathogens, there is a degree of host group pathogen specificity. Enteric viruses are the most specific; in general, human infectious species only infect humans and animal (non-human) infectious species only infect animals.

The host range for protozoa is a little broader, but except for the severely immunocompromised, human infections with *Cryptosporidium* are predominantly associated with genotypes of *C. parvum* carried by humans and livestock (McLauchlin et al. 2000; Chappell & Okhuysen 2002). The livestock genotype can be transmitted to some other animals, but the human genotype is very specific for humans (McLauchlin et al. 2000; Morgan-Ryan et al. 2002). *C. meleagridis* carried by birds has been associated with low numbers of cases (McLauchlin et al. 2000; Pedraza-Diaz et al. 2001).

Bacterial pathogens are the least specific and birds, for example, are known to carry and excrete potentially human infectious *Campylobacter* (Koenrad et al. 1997; Whelan et al. 1983). Birds that live in close proximity to human populations can also transport *Salmonella* (Hernandez et al. 2003; Refsum et al. 2002).

These limitations are important, as enteric illness mediated by waterborne bacteria requires ingestion of much higher numbers of organisms than enteric illness mediated by protozoa or viruses. Dosing studies have found that while ingestion of between one and 10 virus particles or protozoan cysts can lead to infection, at least 1000 and often more than 100 000 bacteria are required (Haas 1983; Regli et al. 1991; Gerba et al. 1996; Okhuysen et al. 1999).

In summary, the study conducted in South Australia found no measurable difference in rates of gastrointestinal illness in children who drank rainwater compared to those who drank mains water. However, there are examples of *Campylobacter* and *Salmonella* enteritis associated with rainwater tanks and one example of cryptosporidiosis/giardiasis associated with an underground tank. Faults in tank design or poor maintenance were identified as contributory factors in some of the investigations of illness.

Dead animals

Entry by small animals and birds to rainwater tanks can lead to direct faecal contamination, even if the animals escape from the tank. In some cases, animals become trapped in tanks and drown, leading to very high levels of contamination. In the case of larger animals, such as possums and cats, this will almost certainly have a distinctive impact on the taste and odour of the water.

Mosquitoes

Rainwater tanks can provide excellent habitats for mosquito breeding. In addition to causing nuisance, certain types of mosquito can be vectors of arboviruses.

Of particular concern are species of mosquito that can be vectors for dengue virus, which occurs in tropical and subtropical areas of the world. Rainwater tanks have been identified as potential breeding sites for vectors of dengue virus and the World Health Organization (WHO) recommends all tanks have screens or other devices to prevent adult mosquitoes from emerging (WHO 1997).

In Queensland it has long been suggested that rainwater tanks are associated with breeding of *Aedes aegypti*, the primary vector of dengue virus (Kay et al. 1984). This was confirmed in an outbreak of dengue in the Torres Strait Islands in 1996–97 (Hanna et al. 1998). In addition, a survey conducted in the Torres Strait Islands in 2002 detected adult mosquitoes, including *Aedes aegypti*, in rainwater tanks with missing or faulty insect screens (Ritchie et al. 2002).

Both Northern Territory and Queensland have regulations relating to prevention of mosquito breeding in rainwater tanks (Northern Territory 1998; Queensland 1996).

Other mosquitoes that breed in rainwater tanks may also be vectors of arbovirus infections. For example, *Ochlerotatus notoscriptus* (formerly *Aedes notoscriptus*) could be a vector of Ross River and Barmah Forest viruses (Doggett & Russell 1997). This species is widespread in Australia.

Chemical hazards

Sources of chemical hazards can be divided into two types:

- those arising from off-site sources beyond the control of the owner/resident, including urban traffic, industrial emissions and poor agricultural practices (for example, pesticide overspraying). In urban areas, potential contamination by lead has attracted most concern, due to its relatively common use, while in rural areas contamination from pesticides has been the major issue
- those arising from on-site sources in the immediate vicinity of the tank, and controllable by the owner/resident. These sources include characteristics of the roof catchment; materials used in construction of the roof, gutters, piping and tanks; flues from wood heaters etc.

Measures introduced in recent years have reduced the potential for contamination from both off- and on-site sources of chemical contamination including:

- off-site
  - introduction of lead-free petrol in the 1980s and lead replacement petrol in 2002
  - tighter controls on industrial emissions
  - increased surveillance and control of pesticide use
- on-site
  - advances in design and construction of tanks and associated equipment
  - development and implementation of standards relating to materials that can be used in contact with potable water or food
  - reduction of lead concentrations in paint from up to 50 per cent before 1950 to a maximum of 0.1 per cent from 1997.

Industrial and urban traffic emissions

In most parts of Australia, industrial and traffic emissions are unlikely to cause significant impacts on the quality of rainwater collected in domestic tanks. In addition, as discussed above, several measures introduced in recent years have reduced levels of airborne contamination and potential impacts on the quality of rainwater collected in tanks.

Analyses of rainwater from domestic tanks in Adelaide (Fuller et al. 1981, South Australian Department of Human Services unpublished results 1999–2002), Newcastle (Coombes et al. 2000, 2002a) and overseas (Haeber & Waller 1987) did not detect an impact from urban emissions on lead concentrations in tank rainwater. However, investigations are required to determine whether urban and industrial emissions in the centre of Australia's largest cities – Melbourne and Sydney – affect tank rainwater quality.

In Adelaide, testing of rainwater from household tanks near industrial precincts was undertaken as part of two investigations into impacts of contaminants associated with local emissions. Lead, manganese, nickel, zinc and hydrocarbon concentrations in the rainwater samples were consistently below the guideline values cited in the *Australian drinking water guidelines* (South Australian Department of Human Services, unpublished results 1999–2002).

Notwithstanding these results, there may be localised areas where tank rainwater quality is affected by specific industries. Relatively high concentrations of lead (mean 61 μg/L) were detected in surveys of tank rainwater collected in Port Pirie, South Australia (Fuller et al. 1981; Body 1986). The source of this contamination is considered to be a very large smelter, and Port Pirie residents have been advised not to use rainwater collected in domestic tanks for drinking or food preparation.

When in doubt about the possible impact of local industry, advice should be sought from the local authority, environmental health agency or environment protection agency.

Pesticides – agricultural pollution

Use of pesticides and potential drift from agricultural areas has been the subject of increasing public concern, and one of the issues commonly raised has been potential contamination of roofs used as catchments for rainwater tanks. There have been complaint investigations but pesticides are rarely detected and, where they are, concentrations are well below health-related guideline values (South Australian Department of Human Services, unpublished results).

In surveys of rainwater quality in rural areas, most samples did not contain detectable concentrations of pesticides (Victorian Department of Natural Resources and Environment 1997; Fuller et al. 1981; Paskevich 1992; New South Wales Environment Protection Authority and Northern Districts Public Health Unit 1996). Endosulfan, profenofos, chlorpyrifos and dieldrin were detected in some samples, but all at concentrations well below health-related guideline values cited in the *Australian drinking water guidelines*.

If in doubt about the use of pesticides in a particular area, advice should be sought from the relevant agriculture, environmental health or environment protection agency.

Bushfires

Bushfires generate large amounts of smoke, ash and debris that can settle on roof catchment areas. In addition, it is possible that fire retardants or foams may also be deposited on roofs.

Such material can be washed into tanks, either when water is applied to the roof as part of fire protecting activities, or when it rains after a bushfire. Although the presence of ash and debris in rainwater does not represent a health risk, it could affect colour, turbidity and taste. The recommended concentrations of the commonly used retardants and foams should not represent a health risk, but they may effect the taste of the water if washed into a rainwater tank.

Slow-combustion heaters

Concerns have been expressed about the potential impact of emissions from slow combustion wood fires on rainwater collected in domestic tanks. Public complaints have ranged from reports of a slight burnt wood taste to tainting with creosote. However, in a survey of rainwater collected from roofs incorporating wood heater flues, polyaromatic hydrocarbon (found in combustion products) concentrations did not exceed guideline values in the *Australian drinking water guidelines* (Victorian Department of Natural Resources and Environment 1997).

Roof materials

Roofs may be constructed from a variety of materials such as cement or terracotta tiles, Colorbond®, galvanised iron, Zincalume®, asbestos/fibro cement, polycarbonate or fibreglass sheeting and slate. All of these should be suitable for collecting rainwater.

LEAD FLASHING/LEAD SOLDER/GALVANISED IRON

Lead flashing has been suggested as a possible source of contamination of collected rainwater but there is little supporting evidence. Leaching of lead into roof run-off may be more of a problem from poorly maintained roofs and gutters, where the process could be increased by the action of water made acidic with organic substances from materials such as leaf litter.

The contribution of building and tank materials to lead in collected water has been examined. Concentrations of lead associated with using galvanised iron in roof or tank construction were acceptable in two surveys (Victorian Department of Natural Resources and Environment 1997; Fuller et al. 1981). In a third survey, Simmons et al. (2001) reported that individually, use of lead solder, lead flashing or galvanised iron in roof catchments was not associated with increased concentrations of lead in tank water. However, increased concentrations of lead were reported when combined data on water collected from catchment areas with lead or galvanised iron in the roof, guttering or spouting were analysed. The lead concentrations detected in the survey were low to moderate and in most cases did not appear to be a major issue, with a 95th percentile of 2 μg/L and a maximum of 14 μg/L compared to the *Australian drinking water guidelines* value of 10 μg/L.

PRESERVATIVE-TREATED WOOD

Preservative-treated wood could be a source of chemical contamination if there is direct contact with rainwater to be collected in a domestic tank. Examples of timber preservatives used in Australia are:

- water-based preservatives, such as copper chrome arsenates and boron compounds
- oil-type or oil-based preservatives, such as creosote
- light organic solvent preservatives, such as solutions containing pentachlorophenol.

CEMENT-BASED OR TERRACOTTA TILES

The coloured surface of cement-based or terracotta tiles will oxidise over time through natural weathering. This oxidised coating may break down and be washed into rainwater tanks, thus colouring the water.

The coating is non-toxic and, if left undisturbed, will settle to the bottom of the tank. The colour may reappear after rain, if settled material is stirred up by water flowing into the tank.

It is possible to purchase colour-through tiles that have colour impregnated throughout the tile, which is more stable.

ASBESTOS/FIBRO-CEMENT ROOFING

Although no longer used in new houses, asbestos may be present in some pre 1970s roofs. Although asbestos fibres are dangerous to health when inhaled in sufficient quantities, it is not believed that asbestos in drinking water poses a risk (*Australian drinking water guidelines*). Asbestos is incorporated into some types of pipe used in distribution of public water supplies.

Note: Asbestos roofing material should, as far as is practicable, be left undisturbed since fibres can be released into the air by actions such as cutting, grinding or drilling. High-pressure roof cleaning methods should also be avoided. Where the roof catchment area has deteriorated badly, it should be replaced with asbestos-free substitutes.

PAINTS AND COATINGS

Before purchasing materials or paint for roofs used to collect rainwater, read and observe the manufacturer's recommendations on labels and brochures. Look for warnings. If in doubt, check with the manufacturer. The three types of paints and coatings are:

- lead-based paints (including primers) – concentrations of lead in paints have been substantially reduced in recent years, but care should still be taken to ensure that paints used are suitable for use in association with collecting rainwater for human consumption
- acrylic paint – will leach dissolved chemicals, including detergents, in the first few run-offs after application and these run-offs should not be collected
- bitumen-based (tar) materials – are generally not recommended, as they may leach hazardous substances or cause taste problems.

Tank materials

Rainwater tanks are available in a range of suitable materials including galvanised steel, Aquaplate®, Zincalume®, fibreglass, plastic and concrete. All can be suitable, providing the materials used are at least of food-grade standard (for example, plastics should comply with AS 2070) and preferably comply with the requirements of AS/NZS 4020 *Testing of products for use in contact with drinking water*.

New rainwater tanks can impart specific tastes and odours. For example, galvanised tanks can impart a metallic taste when first filled, due to leaching of excess zinc.

New concrete tanks can release excess lime, leading to a high pH (Gee 1993; Simmons et al. 2001) and possibly a bitter taste. Rainwater from other types of tanks tends to be slightly acidic (Simmons et al. 2001). Although results outside the recommended pH range of 6.5–8.5 (*Australian drinking water guidelines*) have been recorded, they are unlikely to have a direct health impact, but low pH in particular could cause increased corrosion and result in dissolution of metal tanks, pipes and fittings. By way of comparison, orange juice and some soft drinks have a pH below three.

Other tanks can also impart tastes related to the type of manufacture but, providing the materials are of food or potable water grade, these will not represent a health hazard and will diminish as the tank ages. If tastes make the water unpleasant to use, new tanks may need to be flushed.

It has been suggested that galvanised metal can include low levels of lead, but as discussed in Roof materials above, specific surveys have not detected elevated concentrations of lead associated with metal tanks.

Australian and Australian/New Zealand Standards that apply to tanks and their associated fixtures and fittings are:

- AS 2070 Plastics materials for food contact use
- AS/NZS 2179 Specifications for rainwater goods, accessories and fasteners
- AS 2180 Metal rainwater goods – selection and installation
- AS/NZS 3500 National plumbing and drainage code
- AS/NZS 4020 Testing of products for use in contact with drinking water
- AS/NZS 4130 Polyethylene (PE) pipes for pressure applications.

Further information on types of tank, installation and capacity is provided in Section 7.

Pipework

Pipes that may be in contact with rainwater for extended periods should comply with AS/NZS 4020. In general, this does not apply to guttering or downpipes that deliver directly into the top of rainwater tanks because contact with the water is transient. However, underground pipework delivering water to the tank, between tanks or from tanks to houses should comply with AS/NZS 4020. Polyethylene pipes used for pressure applications should comply with AS/NZS 4130.

Irrigation piping should not be used as it can contain and release lead into water at concentrations exceeding those specified in the *Australian drinking water guidelines*.

Accumulated sediments

Sediments accumulated below good quality rainwater can contain high concentrations of chemicals, including lead (Gee 1993; Scott & Waller 1987; Coombes et al. 2002b). In a survey of water and sediment samples from tanks along the rail corridor used to transport lead ore to Port Pirie, very high concentrations of lead were detected in the sediments, while most of the water samples (25 of 33) contained less than 10 μg/L (Body 1986).

Sediments could be particularly significant in the absence of regular cleaning, as taps are typically close to the bottom of tanks. There have been examples where elevated concentrations of lead have been detected in samples taken from tank taps, due to the presence of small amounts of resuspended sediment from the bottom of poorly maintained tanks (South Australian Department of Human Services, unpublished results).

Dangerous plants

Most plants are harmless but there are some plants in Australian gardens that produce toxins. Examples include:

- fruits of the nightshade family such as *Solanum rantonnetii* and *Solanum nigrum*
- the common *(Nerium oleander)* and yellow oleanders *(Thevetia peruviana)*
- lantanas such as *Lantana camara* and *Lantana montevidensis*
- flowers and berries of white cedar *(Melia azadirachia* var *'australisica')*
- wintersweet *(Acokanthera oblongifolia)*.

Most of these plants are low-growing and would be unlikely to affect above-ground tanks. In addition, there is little evidence of poisoning from plant material in rainwater tanks. However, there are anecdotal reports that flowers of the white cedar falling into tanks can cause diarrhoea (Campbell 2001).

As a general rule, roof catchments should be kept clear of overhanging tree branches and vegetation, and leaf filters should protect inlets to rainwater tanks. These practices will minimise risk from plants.

Further advice on the potential toxicity of plants could be sought from local nurseries or operators of botanic gardens.

Aesthetic quality – tastes and odours

The absence of distinctive tastes and odours is a feature of good quality rainwater, but there is a range of factors and/or conditions that can cause deterioration of these characteristics during collection, storage and piping. Other than dead animals (see Section 4) the principal sources of taste and odour are:

- sediments and slimes at the bottom of tanks or in pipework that can hold stagnant water
- soil and decaying vegetation allowed to accumulate in guttering
- algal growth in pipework or open tanks
- pollen.

Odours from sediments and slimes are the most commonly reported. Sediment can accumulate in the bottom of tanks that have not been cleaned frequently enough. In warm to hot weather, anaerobic conditions can develop, leading to growth of microorganisms that produce sulfides, with a distinctive sewage or rotten egg-like smell.

Pipework that does not completely self drain (for example, u-bends or underground piping from roof catchments to tanks, between tanks or from tanks to buildings) can also be a source of off-tastes and odours, particularly where stagnant water can develop and be retained between rain events. In these environments, slimes and biofilms can be formed and in the same manner as for tank sediments, anaerobic growth can occur, leading to production of sulfides.

Decaying vegetation and soils accumulated in guttering can also release taste and odour compounds into water, particularly if the gutters are not kept clean and do not fully drain between rain events.

Open tanks are fairly uncommon but exposure of stored rainwater to light will lead to algal growth. Most algae are not a human health risk, but growth can adversely affect the taste, odour and appearance of rainwater. Piping that is not impervious to light can also support algal growth.

Some pollens have very distinctive tastes and odours and if allowed to accumulate on roof catchments or in gutters, they can affect the quality of stored rainwater.

Off-tastes associated with roof catchments, that include flues from wood heaters have been reported. Deposits could occur if the heater is not operated efficiently and the flue is not installed and operated in accord with Australian/New Zealand Standards (*see* SAA/SNZ HB170 *Wood heating resource handbook*). The burning of preservative treated wood could exacerbate the problem, and in any event, such wood is not a suitable fuel due to health and environmental concerns associated with production of toxic fumes and ash.

5.

PREVENTIVE MEASURES AND CORRECTIVE ACTION

Health and aesthetic hazards for rainwater collected in tanks can be minimised by sensible preventive management procedures. The possible exceptions are the impacts of urban traffic emissions in highly populated centres, and industrial emissions. Some of the preventive measures are associated with design and installation while others are associated with ongoing maintenance. Well designed systems are low maintenance.

Implementation of a relatively low-key management approach will generally prevent problems occurring so corrective action to restore water quality will be needed infrequently, if at all.

Potential sources of hazards, preventive measures and corrective actions are summarised in Table 2 (human health) and Table 3 (aesthetic quality).

Minimising contamination by harmful microorganisms

Preventive measures to reduce contamination by potentially harmful microorganisms are predicated on minimising the impact of faecal waste. As indicated in Table 2 measures should include:

- keeping roof catchments clear of overhanging vegetation as branches provide roosting points for birds and can provide access for small animals such as rodents, cats and possums
- preventing access by small animals and birds into rainwater tanks by screening all tank inlets and overflows, keeping access hatches closed and by maintaining the integrity of tank roofs
- preventing entry of surface run-off from areas other than the roof catchment into below-ground tanks. Roofs should be secure and the sides and bottom of tanks should be sealed to prevent ingress.

Swimming in storage tanks should be prevented, as this type of human access can greatly increase risks of contamination.

TABLE 2: SOURCES OF POTENTIAL HEALTH HAZARDS AND PREVENTIVE MEASURES

HEALTH HAZARD	CAUSE	PREVENTIVE MEASURE	MONITORING	CORRECTIVE ACTION
Faecal contamination from birds and small animals	Overhanging branches on roof	Prune tree branches	Check tree growth every six months	Prune branches
	Animal access to tank	Protect all inlets, overflows and other openings to prevent entry by small animals and birds	Check access covers are kept closed. Check inlets, overflows and other openings every six months	Repair gaps. Secure access cover. If animal access suspected disinfect tank using chlorine
		Maintain integrity of tank roof and body to prevent access points	Check structural integrity of tank	If a dead animal is found, empty and clean tank. If this has to be delayed, remove remains and disinfect with chlorine
Faecal contamination from humans (above-ground tanks)	Human access to tank	Prevent access. Ensure tank is roofed and access hatches are secured	Check access covers are secured, particularly in hot weather	Secure access cover
Faecal contamination from humans and livestock (below-ground tanks)	Surface water ingress into tank	Ensure tank is protected from overground flows and tank walls are intact	Check structure annually and that surface water does not enter during storm events	Repair or increase barrier to surface water flow. Repair or line inside of tank
Mosquitoes	Access to stored water	Protect all inlets, overflows and other openings with mosquito-proof mesh	Inspect water for presence of larvae at least every six months (in northern areas of Australia this should be done more often)	Repair screening of inlets and openings to prevent access and if larvae are present, to prevent escape of mosquitoes Treat tanks with a small amount of kerosene or medicinal paraffin

HEALTH HAZARD	CAUSE	PREVENTIVE MEASURE	MONITORING	CORRECTIVE ACTION
Lead contamination	Lead based paints and primers on roofs	Do not collect rainwater from roofs painted with products containing high lead concentrations (for example, pre 1970s paint) When painting roof, check suitability with paint retailer		
	Lead flashing on roofs	Paint existing material or use pre-coated products	Inspect roof and gutters every six months	Paint if large amounts of uncoated flashing present
	Increased corrosion of metals due to low pH from long periods of contact between rainwater and leaves	Keep gutters clean. Install leaf protection devices on gutters	Inspect gutters every six months	Clean gutters. If large amounts of leaves are detected on regular inspections clean more often
	Resuspension of accumulated sediment	Regularly clean tank to remove accumulated sediment Reduce amount of sediment by keeping roof catchments and gutters reasonably clean. Protect inlet to tank using a leaf filter. Install a first flush diverter	Inspect tank every 2–3 years Inspect roof and gutters and inlet filter every six months	Clean tank if required Clean roof, gutters and inlet filter as necessary. Ensure filter is in place

HEALTH HAZARD	CAUSE	PREVENTIVE MEASURE	MONITORING	CORRECTIVE ACTION
Other contamination from roof materials	Preservative-treated wood Bitumen based materials	Do not collect rainwater from roofs covered with exposed treated wood Do not collect rainwater from roofs with bitumen-based products	Inspect roof before installing tank	If treated wood present it could be sealed or covered to prevent exposure to rainwater
Chemical contaminants from tanks, pipework etc.	Inappropriate material that does not comply with Aust. or Aust/New Zealand Standards relating to food grade products or products for use in contact with potable water	Use only approved materials	Check suitability of product with retailer or supplier	Remove or replace product
Dangerous plants	Overhanging branches (check identity of suspect plants with horticulturist)	Prune tree branches	Check tree growth every six months	Prune or remove plant

TABLE 3: SOURCES OF AESTHETIC HAZARDS AND PREVENTIVE MEASURES

AESTHETIC HAZARD	CAUSE	PREVENTIVE MEASURE	MONITORING	CORRECTIVE ACTION
Sulfide/rotten egg/sewage odours	Anaerobic growth in accumulated sediment at the bottom of tanks	Regularly clean tank to remove accumulated sediment	Inspect tank every 2–3 years	Clean tank if required. If cleaning not practical (for example, in the middle of summer) disinfect tank with chlorine and flush chlorinated water through all pipework
	Slimes and stagnant water in pipe work	Avoid u-bends or underground pipework that can hold stagnant water. Install drainage points on pipe work		
Musty or vegetable type taste and odours (no light penetration)	Accumulated material on roofs and gutters. Possibly including pollen	Remove overhanging branches from trees. Keep gutters clean. Install leaf protection devices on gutters	Inspect gutters at least every six months	Clean gutters. If large amounts of leaves (or pollen) are detected on regular inspections clean more often
Coloured water	Accumulated damp leaves in gutter	Keep gutters clean. Install leaf protection devices on gutters	Inspect gutters at least every six months	Clean gutters. If large amounts of leaves are detected on regular inspections clean more often
Coloured water, particularly after rain (tiled roof)	Coloured coating from tiles washed into tanks. Re-suspension from sediments when fresh intake	Use colour-through tiles	Inspect water after rainfall	Remove sediment by cleaning the tank

AESTHETIC HAZARD	CAUSE	PREVENTIVE MEASURE	MONITORING	CORRECTIVE ACTION
Musty, vegetable or fishy type taste and odours (light penetration)	Algal growth due to light penetration into tank or pipe work	Make sure tank is completely roofed and is impervious to light	Inspect water every six months	Repair roof
		Ensure pipework, including inlets to tanks, are impervious to light (white pipes can allow light penetration)		Paint pipework with dark colour
Bitter taste (concrete tanks) Metallic taste (galvanised tanks) Plastic taste (plastic tanks)	New tank	Use water from first fill for non-potable purposes. Taste will diminish in subsequent fills	Water quality/taste will improve with tank age	Use water from first fill of new tanks, or water collected from newly painted roofs for non-potable purposes. Problem will diminish with time.
Detergent taste or water frothing	Newly painted roof	Do not collected water from first 2–3 rain events after painting	Water quality/taste will improve with paint age	Use water from first fill of new tanks, or water collected from newly painted roofs for non-potable purposes. Problem will diminish with time.
Hydrocarbon or preservative taste	Deposits from wood combustion heater flue	Install flue in accord with Australian Standards. Operate heater correctly Use appropriate fuel (not preservative treated)	Check flue installation. Check operation of heater and choice of fuel	Repair flue. Discard inappropriate fuel

AESTHETIC HAZARD	CAUSE	PREVENTIVE MEASURE	MONITORING	CORRECTIVE ACTION
Insects/ water boatmen etc.	Access to stored water	Protect all inlets, overflows and other openings with insect proof mesh	Inspect water for presence of insects and/or larvae every six months	Repair screening of inlets and openings to prevent further access Use simple coarse filter to remove remaining insects
Small white flakes in water	Microbial growth	Keep gutters clean. Growth encouraged by nutrients contained in plant and soil material accumulated in gutters or at the bottom of tanks Install leaf protection devices on gutters	Inspect gutters at least every six months Inspect tank every 2–3 years	Clean gutters and tank if necessary Disinfect tank using chlorine
Slime on the inside of tanks	Microbial growth	All containers that continuously hold water will develop biofilms on surfaces below the water level	None required	None required. These are naturally occurring and not harmful to the general population
White deposits on the surface of metal tanks (slimy or waxy feel)	'White rust'. A corrosion product containing zinc-rich oxide	Not required	None required	None required, the deposits are not harmful. Physical removal could damage the surface of the tank and increase the potential for corrosion

Disinfection

Rainwater can be disinfected by chlorination, ultraviolet light irradiation or by boiling.

Chlorination

Regular chlorination of rainwater held in domestic tanks is not considered appropriate in most cases and is generally only recommended as a remedial action. The effectiveness of chlorine is short lived and it will only act on water in the tank at the time of dosing. Fresh run-off into the tank after chlorination will probably not be disinfected.

Chlorination is effective against harmful bacteria, many viruses and *Giardia* but it has limited effect against *Cryptosporidium*. Chlorination can also remove odours from rainwater by oxidising the responsible chemicals. When chlorine is added to water, it reacts with organic matter and other impurities in the water – the amount of chlorine needed for disinfection will depend on the concentrations of these impurities.

To achieve effective disinfection, it is necessary to add sufficient chlorine to provide a free chlorine residual of at least 0.5 mg/L after a contact time of 30 minutes. This can be measured using a suitable chlorine test kit (for example, a swimming pool kit) if available.

As a general guide, the addition of 40 mL of liquid sodium hypochlorite (12.5% available chlorine) per 1000 L of water or 7 g of granular calcium hypochlorite (75% available chlorine) per 1000 L of water will give a reasonable assurance of effective disinfection. Both methods will provide chlorine doses of approximately 5 mg/L. Sodium and calcium hypochlorite can be purchased from large supermarkets, hardware stores or swimming pool stockists. Stabilised chlorine (chlorinated cyanurates) is not effective in enclosed tanks and should not be used.

Methods for calculating the volume of water in a tank are provided in Appendix A.

The chlorine will not make the water unsafe to drink, but it will impart a distinct taste and odour that should dissipate in 10 to 14 days (depending on temperature). Boiling the water will remove most of the taste and odour associated with chlorination.

Calcium hypochlorite should be dissolved in rainwater, in a clean plastic bucket, in the open air, before adding it to the tank. Always add the disinfectant to the water rather than vice versa. When adding the concentrated chemical mixture to the tank, spread it as widely across the surface as possible to promote mixing (this will often be limited by restricted access) and let it stand for at least one hour before use.

Note: When handling and storing chemical compounds, it is important to carefully read and follow safety directions given on the package label.

Ultraviolet light irradiation

Ultraviolet (UV) light irradiation can be used to provide continuous assurance of water quality. UV light systems require relatively low maintenance and have the advantage of not involving addition of chemicals. The UV light could be installed in pipework delivering water from a tank to a dwelling or selectively to taps used to supply water for drinking and food preparation. UV light systems could be particularly suitable for community supplies (see Section 11).

If UV light irradiation is used, it is important to install a system incorporating a sensor that indicates when the device is or is not operational. UV lamps have a limited effective life and most need to be replaced after between nine and 12 months.

Boiling

While rainwater should be safe for most people to drink, at times the microbial quality may not be as high as reticulated water supplies. People with lower immune responses, such as the very young or very old, cancer patients, people with diabetes, organ transplants or those who are HIV positive, should consider boiling the water before consumption. If gastric upsets are being experienced, boiling water should also be considered.

Bringing water to a boil can disinfect rainwater (WHO 2003). Boiling does not have to be maintained for any length of time – kettles with automatic shut-offs are suitable for this purpose. Boiling water will kill any harmful bacteria, viruses or protozoa including *Giardia* and *Cryptosporidium*. The water can then be cooled and stored in a clean container until use. To improve the taste of boiled water, pour it back and forth from one clean container to another, or let it stand for a few hours to increase the dissolved oxygen concentration.

Hot water supplies

Use of rainwater to supply hot water systems has attracted growing interest. Vegetative bacteria, including those that cause enteric illness, are sensitive to heat and Pasteur's original studies indicated that inactivation occurs between 55°C and 60°C. The original low temperature method for pasteurising milk was holding at 61.7°C for 30 minutes; this was increased in 1957 to 63°C to include inactivation of *Coxiella burnetii,* the causative agent of Q fever (Adams & Moss 2000).

Campylobacter, the most commonly detected cause of enteric illness in Australia, is particularly sensitive to heat with inactivation occurring at temperatures above 48°C. At 60°C (minimum storage temperature required for hot water storage by AS/NZS 3500 Part 4.2) 99 per cent kills of *Campylobacter*, *Salmonella* and *E. coli* populations are achieved in minutes (D'Aoust et al. 1988; Feacham et al. 1983). The protozoa *Cryptosporidium* and *Giardia* are also susceptible to heat (Harp et al. 1996; WHO 2003).

In field testing in Newcastle, Coombes et al. (2000) demonstrated that although faecal coliforms, total coliforms and pseudomonads could be detected in rainwater storages, none were present in hot water samples. Total bacterial counts were also substantially reduced by heating. In one case an instantaneous heater was used. Although further investigations on the effectiveness of these units is needed, microorganisms are sensitive to rapid changes in temperature.

Where heating is used as a mechanism to reduce risks from microbial hazards, attention will need to be paid to reliability of heating systems in achieving required temperatures.

Corrective action to improve microbial quality

UNCERTAINTY OVER MICROBIAL QUALITY

Although there have been isolated reports of illness associated with consumption of tank rainwater, for most people rainwater from well maintained roof catchments and tanks represents a relatively low risk of illness. Rainwater is not the most likely source of any of pathogens that cause gastrointestinal illness such as *Giardia*, *Cryptosporidium*, *Campylobacter* or *Salmonella*. Transmission of these organisms by person–person contact or contaminated food is far more common.

If it is suspected that rainwater is contaminated or if additional precautions are sought in the event of illness, water used for drinking and food preparation could be boiled or the tank rainwater could be chlorinated.

ANIMAL ACCESS

Where a rainwater tank has become contaminated by a dead animal, such as a bird or rodent, it is recommended that the tank be drained and cleaned as soon as possible (see Section 5). If the animal is large, such as a possum or a cat, and badly decayed, impacts on taste and odour will be strong and distinct.

If it is not practical to drain and clean the tank immediately, carefully remove as much as possible of the animal carcass and then chlorinate the water as discussed above.

The point of entry for the animal should be located and repaired and sealed.

Filtration

Rainwater collected in tanks should be soft, clear and of good chemical quality.

Water filters should not be necessary as a method for maintaining microbial, chemical or physical quality of rainwater. If problems occur, the preferred approach is to instigate remedial action to prevent contamination (as discussed above) rather than installing a system to treat symptoms of inadequate maintenance.

If water filters are installed, they should be maintained to manufacturer's specifications to avoid problems associated with microbial growths.

First flush diverters

There is some evidence that the first flush of water in a rain event washes the roof catchment and hence may contain higher than average amounts of accumulated dust, bird and animal droppings, leaves and other debris (Coombes et al. 1999, 2002b; Yaziz et al. 1989). Yaziz et al. (1989) showed that, for a small roof, water quality improved once the first 5 L of water passed through the down-pipe from the roof guttering.

Although further investigations are needed to determine how effective first flush diverters are in reducing chemical and microbial contamination in all areas of Australia (for example, in temperate, subtropical and tropical zones), installation of simple devices designed to reduce collection of accumulated debris is still supported. For an average roof catchment it is suggested that the first 20–25 L could be diverted or discarded. First flush devices are commercially available.

First flush devices should be regarded as an additional barrier to reduce contamination and should not be used to replace normal maintenance activities designed to keep roof catchments reasonably clean.

The inlet pipe to all rainwater tanks should be easily detachable so that, when necessary, the tank can be bypassed. Manual detachment could be used as an alternative to an engineered first flush device, although the level of control will not be as good.

Preventing mosquito breeding

Mosquitoes and other nuisance insects need to be excluded from rainwater tanks. Water ponding in gutters also needs to be prevented as it can provide breeding sites for mosquitoes and could lead to eggs being washed into tanks (Northern Territory Public Health Regulations 1998 require that gutters should be installed and maintained to prevent ponding).

Unless in use, all access points, excluding the inlet and any overflows, should be kept shut with close fitting lids that will prevent mosquito access. Inlets and overflows should be covered with closely fitting removable insect-proof screens. Queensland (1996) and Northern Territory (1998) Regulations specify the characteristics of the screens as follows:

- Queensland – brass, copper, aluminium or stainless steel gauze not coarser than 1 mm aperture measure
- Northern Territory – brass or bronze wire not coarser than 7 meshes to the centimetre (each way) and of 33 gauge wire.

Mosquito control

By far the preferred approach for managing mosquitoes and other insects is to keep them out of tanks. In addition, rainwater should not be allowed to pool in containers or on surfaces below tank outlets or taps, as this can also provide a breeding site.

Detection of mosquito larvae (wrigglers) in rainwater tanks indicates the presence of an opening through which the female mosquito can enter and lay eggs or the entry of eggs laid in ponded water collected in roof gutters. Gaps can occur:

- in mesh used to protect inlets and overflows
- around inspection and access points
- between the roof and main body of the tank
- in the tank itself due to corrosion or physical damage.

If mosquitoes or other insects are found in rainwater tanks, the point of entry should be located and repaired and sealed. As well as preventing further access, this will prevent escape of emerging adults. Gutters should be inspected to ensure they do not contain ponded water, and cleaned if necessary.

There is no ideal treatment to kill mosquito larvae present in rainwater. The two commonly recognised treatments involve adding chemicals (medicinal or liquid paraffin or kerosene) to tanks, which defeats one of the advantages of collecting rainwater. In addition, problems have been reported with both types of treatment.

As a last resort, tanks can be treated by adding a small quantity of medicinal or liquid paraffin or domestic kerosene. The recommended dose of kerosene is 5 mL or one teaspoon for a 1 kL tank up to 15 mL or 3 teaspoons for a 10 kL tank. When using paraffin the dose should be doubled.

Note: Commercial or industrial kerosenes, for example, power kerosene for tractors etc., **should not** be used in rainwater tanks.

Paraffin can be used in all types of tanks, but there have been reports of coagulation after a time and of deposits forming on the sides of tanks.

Kerosene is not suitable for use in tanks coated with Aquaplate® and may not be suitable for use in tanks constructed of or lined with plastic. If in doubt, consult the manufacturer of the tank. Used carefully, kerosene will not result in risks to human health, but excess quantities can taint the water and very high doses can be poisonous to humans. Kerosene added to the surface will not mix through the body of rainwater in the tank and it will either evaporate or be washed out of the tank by overflow. Kerosene should not be added to tanks when water levels are low. If excess quantities of kerosene are added to the point that taste is affected, the only solution is to drain and clean the tank.

Internationally, it has been suggested that larvicides, such as temephos, s-methoprene and Bti (*Bacillus thuringiensis*), could be used in rainwater tanks (WHO 1997) but these chemicals are not registered for use in drinking water by the Australian Pesticides and Veterinary Medicines Authority. While permits could be sought, it is unlikely that this approach would receive much support in Australia. In addition the *Australian drinking water guidelines* advise that pesticides (including insecticides) should not be detectable in drinking water supplies.

Note: Vegetable oils should not be used as they can become rancid after a while.

Preventing chemical contamination from on-site sources

Chemical risks from on-site sources can be minimised by sensible management. Preventive measures can include:

- ensuring that pipework in constant or prolonged contact with water complies with AS/NZS 4020
- not collecting rainwater from roofs coated with bitumen-based materials or painted with lead-based paints
- not collecting rainwater from parts of roofs including exposed preservative-treated wood
- ensuring that wood-based heaters and associated flues are designed, installed and operated in accordance with relevant Australian/New Zealand Standards
- not using wood treated with preservatives or painted for fuel in slow combustion heaters
- keeping the use of uncoated lead flashing to a minimum (as a precaution existing lead flashing could be painted)
- inspecting tanks every 2–3 years for the presence of accumulated sediments and, if the bottom of the tank is completely covered, cleaning the tank
- keeping gutters clean to prevent long-term retention of leaf litter and prolonged contact with rainwater. Gutter shields can be used to stop the collection of larger tree and plant material. Gutters should have a sufficient and continuous fall to prevent pooling of water. Prolonged contact of water with leaves can lower pH resulting in increased corrosion and release of metals.

Preventing impacts on aesthetic quality

The presence of suspended material or the generation of off-tastes and odours from accumulated material or algal growth can affect aesthetic quality. The possible presence of suspended material can be minimised by keeping the roof catchment reasonably clear of accumulated debris, including leaves and twigs, and by keeping gutters clean. Roofs and gutters should be cleaned twice a year or more frequently in areas subject to large amounts of windborne dust or leaves.

Generation of tastes and odours can be prevented by:

- keeping gutters clean and ensuring they drain quickly between rain events
- preventing entry of light into tanks or pipe work; some types of white pipes allow transmission of light and should be painted with a dark colour
- removing accumulated sediment
- installing pipe work so it is self-draining or installing drainage points to enable pipes to be emptied and flushed.

Removing odours and suspended material

If rainwater has a distinctive odour or contains suspended material, the most likely sources are accumulated material in gutters, at the bottom of tanks or stagnant water in pipe work that does not self-drain.

Corrective action should include inspecting gutters and the bottom of tanks and determining whether there is pipe work that can contain stagnant water. If necessary, gutters and tanks should be cleaned and pipe work drained. Where possible, a drainage point should be fitted in pipe work that does not self-drain.

It is not always practical to clean a tank immediately, particularly if it is the only source of drinking water. In addition, off-odours from pipe work and accumulated tank sediments are more common in hot or warm weather in the absence of likely replenishing intakes of water. In this case, chlorinating the tank can provide a temporary solution until cleaning can be undertaken (for example, at the beginning of winter or the wet season). Any pipe work, including inlets to tanks, that does not completely drain, should be flushed with chlorinated water. The dose rates in Section 5 Disinfection are suitable.

Bushfire debris

Ash and debris deposited on a roof should be removed and the first flush of water after a bushfire should not be collected. If material has been washed into a tank in sufficient quantities to affect taste or appearance of rainwater, the tank will need to be drained and cleaned, or alternatively the water could be used for non-potable purposes.

Tank desludging

All tanks should be examined for accumulation of sediments every 2–3 years, or if sediment is evident in the water flow. As discussed in Section 4, accumulated sediments can be a source of chemical contamination and off-tastes and odours.

Sludge can be removed by siphoning without emptying the tank. To do this, use an inverted funnel in the end of a hose and move it carefully across the bottom of the tank. The sludge, plus the lower portion of water in the tank, can be released to waste. If leaves and coarser debris are present in the sludge, a siphon hose of approximately 50 mm diameter should be used.

Sludge may also be pumped from the tank with minimum loss of water by using a suitable motor-operated pump and attachments.

Finally, sludge can also be removed by draining and cleaning the tank. If a drain plug is provided at the base of the tank, water can be run to waste to discharge the sludge. Once the tank is empty, the remaining sludge can be scooped up and removed through the access opening. Care should be taken not to disturb the protective film on the inside surface of the tank.

Tank cleaning businesses (generally listed in telephone directories) may also be available to desludge tanks.

Organic material removed from the tank may be disposed of in the garden by spreading and digging into garden beds. Environment protection agencies should be consulted about off-site disposal.

Tank cleaning

Where cleaning necessitates entering the tank, take care to ensure adequate ventilation is provided and an additional person is in attendance. Advice on working in confined spaces should be available from occupational, health, safety and welfare authorities in each State and Territory.

It is important to check the structural condition of the tank before choosing a method of cleaning. Cleaning should generally be limited to removing accumulated sediments, leaf litter etc. Harsh cleaning methods may accelerate deterioration, for example, removing the protective layer on the inside walls of a steel tank will lead to tank corrosion. So called ‘white rust’ caused by zinc-rich oxides on the inside of metal tanks is not a health risk and does not need to be removed.

Cleaning agents that might release hazardous fumes or adversely affect water quality after cleaning should not be used. After cleaning, it is recommended that the internal walls and floor of the tank be rinsed with clean water. Rinse water and sediment should be run to waste.

Discarded water should be diverted away from tank foundations, buildings and other structures. Water containing cleaning agents should not be allowed to flow into street guttering.

6.

MONITORING AND MAINTENANCE

In a similar fashion to all drinking water supplies, rainwater systems need to be monitored. Monitoring of domestic rainwater tanks consists of a range of visual inspections rather than laboratory testing of rainwater quality. The recommended regime of inspections and associated maintenance is not particularly onerous, but it is necessary for quality assurance. A proactive approach will prevent development of problems that can lead to deterioration of water quality. Tables 2 and 3 provide an overview of monitoring requirements and corrective actions.

Once a rainwater tank is installed, it is recommended that the following components of the roof catchment and tank be inspected at least every six months:

- Gutters – generally will need cleaning as well as inspection. If inspection finds large amounts of leaf material or other debris, then inspection and cleaning frequency may need to be increased.
- Roof – check for the presence of accumulated debris including leaf and other plant material. Accumulated material should be cleared. If tree growth has led to overhanging branches these should be pruned.
- Tank inlets, insect-proofing and leaf filters – if necessary these should be cleaned and repaired.
- Tank and tank roof – check structural integrity of the tank including the roof and access cover. Any holes or gaps should be repaired.
- Internal inspection – check for evidence of access by animals, birds or insects including the presence of mosquito larvae. If present, identify and close access points. If there is any evidence of algal growth (green), find and close points of light entry.
- Pipework – check for structural integrity. Sections of pipework that are not self-draining should be drained.

In addition to six-monthly inspections, tanks should be inspected every 2–3 years for the presence of accumulated sediments. If the bottom of the tank is covered with sediment the tank should be cleaned.

Initial inspection on moving into a house with a rainwater tank

On moving into a house with a rainwater tank all the above steps should be undertaken. In addition, a wider inspection should be conducted to gain an understanding of the physical characteristics of the roof catchment area, storage tank and any associated pipework including whether:

- the tank and tank roof are in reasonable condition with no obvious holes or gaps that would allow ingress of small animals, insects or light
- water in the tank is clear and has no obvious odours
- the tank inlet is protected by a leaf litter guard and that all permanent openings (inlet, overflows etc.) are covered by mosquito-proof screens
- pipework is either self-draining or has drainage points installed
- there is a cross connection with the public mains water. If there is, it should be confirmed that this has been done in accordance with local requirements (check with the water supply authority – see Section 7)
- there is any exposed preservative-treated timber or large amounts of uncoated lead flashing
- there is a flue from a slow combustion heater and, if there is, that it is installed in accordance with Australian Standards.

Any remedial action should be instituted as soon as possible.

Local, regional and State health authorities can be a valuable source of advice and/or information on rainwater tanks including local and State requirements.

Water quality testing

Regular chemical or microbiological testing of domestic rainwater tanks is not needed, but rainwater used for any commercial purpose or for community-based supplies will require testing to verify suitability for drinking (see Section 11).

Microbial testing of rainwater from domestic tanks is rarely necessary and in most cases is not recommended. Water quality in rainwater tanks can change rapidly during wet weather and, during dry periods, numbers of indicator bacteria (*E. coli*) and faecal pathogen numbers decrease due to die-off (National Research Council 1998). Testing for specific pathogens is often expensive and is generally only warranted as part of an outbreak investigation. If there are strong concerns about water quality, chlorination of tank water could be a suitable alternative to testing. If microbial testing is undertaken, the parameter of choice is *E. coli* as an indicator of faecal contamination. Tests for total coliforms or heterotrophic plate counts are of little value as indicators of the safety of rainwater for drinking.

Chemical testing should only be required in exceptional circumstances, such as in specific areas where there are concerns about impacts of major industrial or agricultural emissions. In these circumstances the chemicals of concern need to be identified before testing or large costs can be incurred with limited likelihood of successful detection.

Advice on the need for testing and analytical laboratories should be sought from local water or environmental health authorities. When testing is performed, results should be compared to the values contained in the *Australian drinking water guidelines*.

7.

CONSTRUCTION MATERIAL, SIZE AND INSTALLATION

Galvanised steel tanks

The most common material used in the manufacture of rainwater tanks is galvanised steel. Galvanised steel is not inherently resistant to corrosion but it is available with rust-resistant coatings such as Zincalume® or Aquaplate® (see below). Initial corrosion of galvanised steel normally leads to production of a thin adherent film that coats the surface of the tank and provides protection against further corrosion. It is important when cleaning such tanks not to disturb this film.

New tanks may leach excess concentrations of zinc, which could affect the taste of stored rainwater, but is not a health risk. These tanks may need to be flushed before use.

Aquaplate® steel has a food-grade polymer skin that complies with Australian Standard AS 2070, bonded to a corrosion-resistant galvanised steel base. A number of precautions need to be taken with tanks manufactured using Aquaplate®:

- the polymer coating is not resistant to prolonged exposure to sunlight so tanks must have a top cover in place at all times
- kerosene or similar chemicals used as mosquito larvicides can cause degeneration of the polymer coating and should not be used
- the polymer coat should not be damaged when cleaning or installing the tank. If the coating is damaged, it should be repaired immediately using an appropriate sealant to prevent corrosion of the metal portions of the tank.

As well, copper or copper alloy fittings (brass and bronze) should not be connected directly to steel tanks as this causes corrosion. A minimum of two metres of plastic pipe should be used between the tank and copper fittings.

Concrete tanks

Concrete and ferro-cement tanks are strong and long lasting and can be installed underground.

New tanks may impart tastes and may leach lime, thereby increasing the pH of water. These tanks may, therefore, need to be flushed before use.

Fibreglass tanks

Fibreglass tanks suitable for collecting rainwater are available. These tanks are manufactured with a food-grade coating on their interior surface. The coating is cured before the tanks are offered for sale. The tanks should also be manufactured to prevent the entry of light, which could encourage algal growth.

Plastic tanks and tanks with plastic liners

Increasing ranges of tanks manufactured from synthetic polymers including polyethylene are becoming available. Plastic tanks and plastic liners should be constructed of materials that are at least of food-grade standard (compliant with AS 2070) and preferably that comply with the requirements of AS/NZS 4020. Plastic tanks should be manufactured to prevent the entry of light.

Size of tanks

Where a rainwater tank is intended to provide a supplementary source of water, the size of the tank will depend on a balance of cost, against the range of uses required (drinking, food preparation, bathroom, laundry, toilet etc.).

If the rainwater tank is to represent the only source of potable or domestic water, cost will be less important than the size of tank needed to provide security of supply. In this circumstance the size of the tank will depend on:

- the volume of water needed
- the amount and pattern of rainfall
- the area of the roof catchment
- the security of supply required.

The amount of rain combined with the area of the roof catchment will determine the maximum volumes of water that can be collected. If this is not sufficient, then either a greater catchment area will be needed (for example, garage or shed) or water demand will need to be reduced. A number of water conservation measures could be applied, including dual flush toilets or dry toilets (if permitted), and water efficient devices, such as reduced-flow shower heads, washing machines with suds savers etc. If, after implementing these measures, the volume of rainwater that can be collected is not sufficient to meet demand, water will need to be obtained from an additional source (see Section 9).

Experience is always a useful guide and advice should be sought from neighbours particularly in areas where reliance on rainwater tanks is common. Some State government departments have tables of calculated tank sizes based on local rainfall patterns. In Queensland this information is available from Water Wise (Environment Protection Agency), in South Australia from the South Australian Water Corporation or the Department of Water, Land and Biodiversity Conservation and in Western Australia from the Department of Agriculture. Other departments with responsibilities for water resources or water supply may also provide this information.

In some areas local authorities specify minimum requirements for water storage and there may also be storage requirements associated with firefighting. The local council or local fire authority should be contacted to determine whether such requirements apply.

Volume of water needed

The volume of water needed may vary from one area to another. Water demand will depend on:

- the number of people using the water
- average consumption per person
- the range of uses (drinking, food preparation, bathroom, laundry, toilet etc.)
- the use of water conservation devices.

In areas supplied with reticulated water, the average indoor use per household is estimated to be in the range of 300–740 L per day or alternatively about 100–200 L per person per day (see Section 1). These volumes are steadily decreasing with the application of water conservation measures. Advice on water usage could be sought from the local water or water resources authority.

Average rainfall

In general, the most accurate source of rainfall information is the Bureau of Meteorology. In addition to average rainfall (annual and monthly) it is important to consider yearly variations, seasonality of rainfall and the occurrence and length of dry spells.

Area of roof catchment

Calculate the area covered by the parts of the roof from which the water is to be collected. It is the flat or plan area (including eaves) that should be determined. The slope or pitch of the roof and the actual area of tiles or metal is not important.

The average roof area for a small house is about 100–150 m^2, for a medium house about 150–200 m^2, and for a large house can be 200 m^2 or greater.

Security of supply

The size of the tank needed will be influenced by the degree of security required. As used in this monograph, securities of 90 per cent or 99 per cent mean the rainwater tank should supply the demand of water calculated for 90 per cent or 99 per cent of the time, respectively.

Maintaining water supply under almost all conditions, including extended dry spells (high security), will require a larger tank than that needed to maintain supply under normal or average conditions (lower security). Lower security will mean water rationing or alternative sources of supply (see Section 9) may have to be used more frequently.

As a guide, tank sizes for 99 per cent and 90 per cent security for a temperate climate are shown in Appendix B.

Calculation of tank size

Methods for determining the maximum amount of water that can be collected as a function of rainfall, and roof size and tank size needed to provide security of supply throughout the year are provided in Appendix B.

Installation

Rainwater tanks should be installed in a manner that will minimise the risk of contamination from industrial pollutants, dust, leaves, pollens, pesticide sprays, fertilisers, debris, vermin, birds, small animals and insects. Tanks should not be allowed to provide breeding sites for mosquitoes.

Underground tanks require additional protection against entry of surface run-off or groundwater, animal or human faecal material (including septic tank waste) and soils. These tanks need to be properly sealed and access points need to be protected against ingress of surface run-off. Maintenance and cleaning of underground tanks might be more difficult.

Interconnection with mains water supplies

Rainwater tanks should **never** be interconnected with mains water supplies without determining local requirements. Protection of mains water distribution systems from other sources of water is an extremely important public health requirement and inappropriate cross-connections have been identified as sources of waterborne outbreaks (Craun & Calderon 2001).

Water authorities do not allow direct connection of rainwater systems with reticulated water supplies or alternatively, as a minimum, require the use of backflow prevention devices to stop rainwater siphoning back into the reticulated supply.

Information should be sought from the local water authority.

Covers and lids

Tanks should have impervious covers and all access points, except for the inlet and overflow, should be provided with close-fitting lids which should be kept shut unless in use. The inlet to the tank should incorporate a screen to prevent material, such as leaves etc., that may have collected on the roof or in gutters, being washed into the tank and a mesh covering to prevent access of mosquitoes and other insects. Overflows should also be covered with an insect-proof mesh.

Tanks should be light-proof to minimise algal growth. Most algae will not make water unsafe for human consumption but can adversely affect the taste, odour and appearance of the water.

Bypass or overflow water

Run-off that is not collected in the tank and/or overflows should be diverted away from tank foundations, buildings or other structures. This water should be directed onto gardens or into the stormwater drain; it should not be allowed to pool or to cause nuisance to neighbouring properties or to areas of public access. Local authorities may have regulations or requirements that apply to diverted or excess rainwater flows.

Inlet pipes

Wherever possible, all sections of inlet pipes should be directed down and rainwater should flow into the top of the tank. The inclusion of rising sections will provide potential traps for sediments, biofilms and stagnant water and these should be avoided. Modifications to existing downpipes should not restrict existing water flows from roof gutters. To maximise the collection of rainwater, the downpipes should be of sufficient diameter to accept all water flow from roof gutters, even in heavy rains.

Catchment

Before installing a rainwater tank, the roof catchment should be checked for:

- overhanging vegetation – should be pruned
- a flue from a slow combustion heater – if possible this section of roof should be avoided; if not ensure the flue is installed in accord with Australian/New Zealand Standards
- overflows/discharges/bleed-off pipes from roof-mounted appliances, such as evaporative air conditioners, hot water services, and solar heaters – should not discharge onto the rainwater catchment area
- large amounts of uncoated lead flashing – should be painted
- exposed preservative-treated timber – should be sealed or the section of roof containing the timber should not be used for collection of rainwater.

Gutters should have sufficient and continuous fall to downpipes to prevent pooling of water, which could increase accumulation of material, lead to algal growth and possibly provide a site for mosquito breeding. A fall of one in 100 should be sufficient.

Gutter shielding devices will substantially reduce the amount of larger debris (bark, larger leaves, etc.) but small particles will not be removed. Periodic cleaning will still be needed but at a lower frequency than for gutters without shielding.

8.

TANK RAINWATER TO SUSTAIN DEVELOPMENT

There are two common justifications for installing rainwater tanks. The first and most important is one of necessity in areas not served by mains water and where safe supplies of water are in short demand. The second is to provide a source of water that can be used as an alternative to mains water.

In areas without mains water

Rainwater tanks can provide a valuable source of drinking water in areas not supplied by mains water. Even in arid regions with low rainfall, tanks can provide a valuable resource. Conway et al. (1999) examined rainwater harvesting in an arid location (Giles) in central Australia where the median rainfall is only 119 mm per year. In an average year, a house with a 266 m^2 roof area could collect 61.25 kL of water in a 27 kL tank and provide 168 L of water per day. In the worst rainfall year in 40 years, 9.5 kL could have been collected to provide 26 L per day. While these volumes would not be sufficient as a total resource, they could represent a substantial source of drinking water to augment a secondary source, such as groundwater used for other domestic purposes. This could be particularly important in areas where groundwater is too saline to drink.

At Mutjitjula (in the Northern Territory), with an average yearly rainfall of 300 mm, rainwater tanks have been installed to provide a minimum of 100 L of rainwater per day to seven houses (Grey-Gardner 2002). The community initiated the project to supply a better-tasting alternative to the local groundwater supply. The system was designed to provide ease of management in a remote area with limited access to water. To provide greater assurance of water quality each house was fitted with a point-of use filter.

In areas with mains water

Mains water is used for purposes ranging from drinking and food preparation to toilet flushing and garden watering. The use of rainwater tanks as an alternative source of water for any of these purposes has the potential to reduce pressure on the limited surface and groundwater resources used to supply reticulated water to urban and rural communities. Reduced pressure on the reticulated supply provided by rainwater tanks could alleviate the need for additional dams in growth areas and the increases in cost of producing water for all uses to drinking water standard.

One constraint that has been raised is lack of space in large urban centres limits the size of tanks that can be installed. This problem is being exacerbated by the trend to higher density living. In these circumstances, at best, only small-capacity tanks can be installed.

Although small tanks will overflow during wet seasons, modest 1–2 kL tanks, which require little room, can capture a significant proportion of roof run-off. The proportion able to be collected is largely a function of volume and frequency of use. A household using rainwater for all domestic purposes will empty a small tank more often and hence increase the available storage when a rain event occurs. On the other hand, less storage will be available in households using rainwater just for drinking and food preparation. Garden watering is a high volume use, but it mostly occurs in drier months when replenishing rain is relatively infrequent, leading to long periods when small tanks will contain no rainwater.

Across Australia, average rainfall, patterns of rainfall, and residential water usage vary. In the capital cities rainfall ranges from 500–1600 mm per year (Bureau of Meteorology) while indoor water usage varies from an estimated 150 kL to 350 kL. Hot water represents about 30–35 per cent of indoor use. These data have been used to calculate volumes that could be collected in 1 kL and 10 kL tanks and where the water is either used to supplement mains water for all indoor uses or just for hot water uses (see Table 4).

In Adelaide, for example, which has an average rainfall of just above 500 mm, about 57 kL of water would flow from a medium-sized roof of 150 m^2 each year (see Table B.4). Using data on rainfall patterns over the past 10 years, a 10 kL tank supplying water for all types of indoor use could collect most of the 57 kL. This would represent about 36 per cent of annual use (160 kL). A small tank of 1 kL could still collect and contribute 39 kL or 24 per cent of total household use.

If rainwater was used just to supply hot water, a 10 kL tank could contribute 37 kL and a 1 kL tank 25 kL per year or 65 per cent and 44 per cent respectively of the available roof run-off. Potential volumes of water that could be collected in 1 kL and 10 kL tanks in all Australian capital cities are shown in Table 4.

TABLE 4: INDICATIVE VOLUMES OF WATER COLLECTED IN RAINWATER TANKS IN AUSTRALIAN CAPITAL CITIES

CITY	POTENTIAL VOLUME OF WATER COLLECTED PER YEAR (KL)*			
	1 kL tank		10 kL tank	
	for hot water supply	total indoor supply	for hot water supply	total indoor supply
Adelaide	25	39	37	57
Brisbane	33	48	54	110
Canberra	32	52	44	82
Darwin	35	67	53	135
Hobart	37	48	47	78
Melbourne	40	56	54	87
Perth	26	51	40	87
Sydney	38	49	55	97

* from a 150 m^2 roof.

Source of data: M Allen, Department of Water, Land and Biodiversity Conservation (SA). Figures were derived from a daily water balance model using long-term rainfall data for each capital city and estimates of water use based on consumption for each city by a household with three occupants.

Other combinations of use would provide different proportions of collection. Mitchell et al. (1997) determined that for a house with a roof area of 203 m^2 and with three occupants, use of rainwater from a 13 kL tank for laundry, toilet and outdoor use could achieve use of 49–56 per cent of available roof run-off and a 30–40 per cent reduction in mains water use.

In practical examples, the 'Healthy House' in Queensland used a 22 kL tank to collect rainwater from a 120 m^2 roof. In 2000–01 the tank supplied 165 kL (36%) of 458 kL used for total indoor use by a family of five (Gardner et al. 2002). The 'Sustainable House' in Sydney uses a 10 kL tank to collect rainwater from a small roof of 70 m^2 to supply 230 L of water per day for all internal uses, except toilet flushing (Mobbs 1998). Coombes et al. (2000) showed that use of rainwater for hot water and toilet flushing from shared storages in the 'Figtree Place' development could provide up to 45 per cent reduction in mains water use. In a subsequent study at Maryville, Newcastle where rainwater was collected in a 9 kL tank and used for hot water, toilet flushing and limited outdoor use, 28 kL of rainwater was used from the tank over 24 weeks (39% of available roof run-off) (Coombes et al. 2002c). During this period, only 25 kL of mains water was used in the house, representing a 52 per cent reduction.

In addition to reducing consumption of mains water, household use of rainwater also reduces flows of stormwater into street gutters and then to receiving waters. Although house roofs only provide a fraction of the total urban surface run-off, even small tanks reduce these flows (for example, see Mitchell et al. 1997; Coombes et al. 2002a). A detailed discussion of this issue is beyond the scope of this monograph.

Costs and benefits of rainwater tanks

There are several issues to consider when installing a rainwater tank. As well as the cost of the tank itself these can include:

- transportation
- installation
- alterations to gutters and downpipes
- a tank stand or foundation
- additional plumbing
- a first flush device
- insect-proof screening and gutter guards
- a pump (if necessary)
- maintenance
- development approval (if required).

Estimates of the cost of rainwater from domestic tanks have varied from $0.3 to $14 per kL (ACTEW 1994; Van der Wel 2000; Coombes et al. 2002c). To a certain extent, a degree of variation is to be expected, as a range of factors will influence costs. These factors include:

- whether the rainwater tank is to be the sole source of supply or a supplementary supply (the former requires a larger storage capacity)
- the range of uses, for example, using rainwater to supply hot water in a house will require less additional plumbing compared to substituting rainwater for parts of the cold water supply in an existing house
- whether installation is part of new construction or is a retrofit to an existing dwelling
- amount and seasonality of rainfall.

Most estimates have been limited in scope to determining the cost to the householder or installer of the tank. This approach reflects the general situation where the choice or decision to install a rainwater tank has largely been an independent and individual process. However, this excludes the potential benefits to the community of installing rainwater tanks, particularly if it was done in a coordinated way (for example, Coombes et al. 2002a). It has been suggested that installation of rainwater tanks in all new and redeveloped dwellings could provide community savings through reducing demands on reticulated water supplies, delaying the need for new water supply infrastructure and reducing the need for spending on stormwater infrastructure (Coombes et al. 2002a Pezzaniti 2003).

There is evidence of increased recognition of potential community-wide benefits of installing rainwater tanks. In 2002–03, when water restrictions were imposed in many parts of Australia, potential benefits of rainwater tanks received greater attention. Offers of financial support, in the form of rebates, expanded to include Victoria, Sydney and Brisbane. A rebate has been available for some time in the ACT, while some local councils have also provided financial support.

In a few areas, local councils require installation of rainwater tanks with new dwellings and some developments are being designed with rainwater tanks included for all dwellings. Most of these programs have promoted outdoor use, together with indoor use for toilet flushing, laundry and, in some cases, hot water supply.

On a note of caution, householders have a poor record of maintaining rainwater tanks. In developments where rainwater tanks are included for all dwellings, depending on the nature of use of the water, it may be necessary to institute a centralised management system. This would increase costs.

In addition, in areas where rainwater tanks potentially provide breeding sites for mosquito vectors or viruses, such as dengue, the potential for inadequate maintenance has cost implications. Queensland and the Northern Territory have specific legislation relating to mosquito control, and monitoring and enforcement of compliance imposes costs. In the worst case scenario, illness and intervention programs associated with rainwater tanks would have cost implications.

9.

OTHER SOURCES OF WATER

In some cases it may be necessary to augment rainwater in tanks with water from other sources such as bores, dams, rivers and creeks or with carted water.

Only water that is suitable for the purpose intended should be used. If the water is to be used for drinking and food preparation, it should comply with the *Australian drinking water guidelines* (possibly after chlorination). If there are any doubts about the suitability of a water source, consult the local or State water or environmental health agency and, if necessary, have the water tested before adding it to the tank.

Surface water

Water subject to contamination from human or livestock waste, such as dams, rivers and creeks, can contain a wide range of pathogenic organisms including chlorine-resistant *Cryptosporidium*. Water of this type may not be suitable for drinking even after disinfection.

Surface water that is protected from human and livestock waste can be used. Water should be added to the tank in one action, chlorinated and allowed to stand for at least one hour before use.

Chlorination should be performed as described in Section 5 using a test kit to measure chlorine residuals. If, 30 minutes after chlorination, the free chlorine is not at least 0.5 mg/L, a second equal dose should be added. If a kit is not available, use double the amount of chlorine recommended in Section 5.

Deep groundwater, confined aquifers

Water from a deep, encased and well maintained bore and/or from a confined aquifer will generally not need disinfection after addition to a rainwater tank, but the chemical quality of some groundwater is not suitable for drinking. Only groundwater that is compliant with guideline values cited in the *Australian drinking water guidelines* should be used. Key health parameters for groundwater are arsenic, nitrate, fluoride and health-related heavy metals. Salinity is an important aesthetic parameter.

State or regional water resource agencies should be able to provide general information on local groundwater characteristics.

Shallow groundwater

Groundwater from shallow or unconfined aquifers is readily contaminated by agricultural, industrial or urban activities and generally should not be used as a source of drinking water unless recently tested for microbial and chemical quality (for example, for arsenic, nitrate, fluoride, health-related heavy metals, petroleum hydrocarbons and other organic chemicals).

Carted water

Drinking water is recognised in Australia as a food and, depending on State legislation, water carters may need to be registered as a food business. If supply of additional drinking water is needed, local authorities should be able to provide names of suitable water carriers/carters that are registered or that the authorities are satisfied will provide water suitable to drink. In the absence of information from local authorities, make sure the water carrier/carter can provide evidence that water supplied will be safe to drink. This evidence could include:

- any authorisations issued for the purpose of supplying drinking water
- compliance with State food legislation including, where required, that they have notified the local council or appropriate health authority that they are a food business
- the identity and quality of the source water
- evidence that tankers used are suitable for the purpose of carrying drinking water (for example, not likely to have carried other materials that would contaminate drinking water).

10. LEGISLATION

While there is increasing government support for using rainwater tanks in Australia, there are legislative requirements in many areas relating to installation and design. In some areas, where mains water is not available, there are requirements associated with supply of water for firefighting. In addition, as discussed in Section 5, both Queensland and the Northern Territory have regulations relating to prevention of mosquito breeding.

Cross-connection of a rainwater tank with a mains water supply should never be undertaken without consulting the local water authority. There are generally restrictions in place including mandatory use of back-flow prevention devices to prevent the possibility of water from tanks entering mains water supplies.

Discharge of treated water or disposal of accumulated sludge may also be subject to local or State regulations.

There are additional legislative requirements relating to tanks used as a source of community supplies (see Section 11).

Before purchasing or installing a rainwater tank, it is important to establish whether there are any local health, building or planning regulations associated with rainwater tanks. The local council or regional authority with jurisdiction over these regulations should be consulted.

11. COMMUNITY-BASED SUPPLIES

Community-based drinking water supplies need a higher level of management than those to individual dwellings. Operators/managers of community-based supplies need to implement more formal documented management plans to assure quality. In addition, in Australia, drinking water is regarded as a food and operators of community supplies should contact relevant health authorities to determine requirements under State food legislation.

If rainwater is supplied for purposes other than drinking and food preparation, this must be clearly indicated on all taps.

The principles discussed in Section 3 are relevant to community-based supplies, but compared to management of rainwater tanks used in individual dwellings, a greater surety is required due to the potential exposure of larger numbers of people. The need for surety is further increased if rainwater tanks are used in facilities such as nursing homes, hospitals or in food premises. Use of continuous disinfection, for example, through installation of a monitored ultraviolet light system could be required to provide assurance of water quality.

Documented management plans for community supplies should include a flow diagram of the system (catchment area, storage tanks, pipework, tap locations) together with a description of preventive measures, monitoring and corrective actions as well as evidence that these requirements have been met. In addition, while preventive management and maintenance procedures should always remain the primary focus for assuring water quality there is a need for verification that the overall plan works effectively.

A traditional approach to verification is regular testing for the faecal indicator, *E. coli*. The frequency of testing (for example, weekly or monthly) will depend on the size of the supply and whether water supplied from tanks is treated. For example, installation of a monitored ultraviolet light disinfection system could lessen the required frequency of testing. If *E. coli* is detected, remedial action will be required. This could include chlorination of the rainwater tank. The presence of *E. coli* in a disinfected supply indicates inadequate treatment and the need for improved performance.

If a community-based supply is in an area subject to industrial emissions or high levels of urban traffic, chemical testing could also be warranted.

Further information on requirements for management of water quality is available in the *Australian drinking water guidelines*.

12. FLUORIDE

Many mains water supplies are dosed with fluoride to provide protection against dental caries. This practice is supported by the National Health and Medical Research Council (NHMRC 1991) and the Australian Dental Association. Rainwater collected in domestic tanks will not contain fluoride, but it is not recommended that tank water should be dosed.

Alternative sources of fluoride include fluoridated toothpastes and fluoride supplements. Where rainwater is used as a major source of water for drinking and food preparation, advice concerning fluoride should be sought from the local dentist, school or community dental service or from the Australian Dental Association.

13. FURTHER ADVICE

Public Health Units

New South Wales	Environmental Health Branch New South Wales Health Department PO Box 798 Gladesville NSW 2111 Phone: (02) 9816 0589 Facsimile: (02) 9816 0377
Victoria	Environmental Health Unit Department of Human Services GPO Box 1670N Melbourne Vic. 3001 Phone: (03) 9637 4156 Facsimile: (03) 9637 4507
Queensland	Environmental Health Unit Queensland Health GPO Box 48 Brisbane Qld 4001 Phone: (07) 3234 0938 Facsimile: (07) 3234 1480
Western Australia	Environmental Health Directorate Health Department of Western Australia PO Box 8172 Perth Business Centre WA 6001 Phone: (08) 9388 4999 Facsimile: (08) 9388 4955

South Australia	Environmental Health Service Department of Health PO Box 6 Rundle Mall Adelaide SA 5000 Phone: (08) 8226 7100 Facsimile: (08) 8226 7102
Tasmania	Environmental Health Services Department of Health and Human Services GPO Box 125B Hobart Tas. 7001 Phone: (03) 6233 3555 Facsimile: (03) 6233 6620
Northern Territory	Environmental Health Program Department of Health and Community Services PO Box 40596 Casuarina NT 0811 Phone: (08) 8922 7340 Facsimile: (08) 8922 7200
ACT	Health Protection Service Locked Bag 5 Weston Creek ACT 2611 Phone: (02) 6205 1700 Facsimile: (02) 6205 1705

Advice on water quality and testing

Advice on water quality and testing could be obtained from the local health or water authority. The latter could be a government or local government agency or a water corporation.

Advice on tank size

Advice on determining the required size of rainwater tanks should be sought from the State or local agency responsible for management and control of water resources.

A.

DETERMINING THE SIZE OF INSTALLED TANKS (FOR CHLORINATION)

Tank sizes range from small modular tanks of 750 L (~165 gallons) to over 50 000 L (~11 000 gallons). To convert a volume in gallons to a volume in litres, multiply the number of gallons by 4.5.

Methods to calculate the volume of tanks are given below.

To calculate the volume of a **rectangular** tank, use the formula:

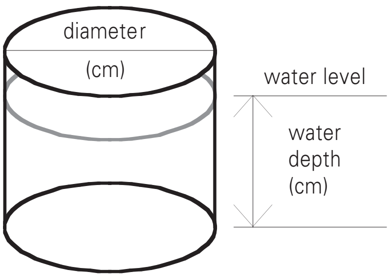
Volume (in litres) = depth (cm) x width (cm) x length (cm) ÷ 1000

To calculate the volume of a **cylindrical** tank either use the formula:

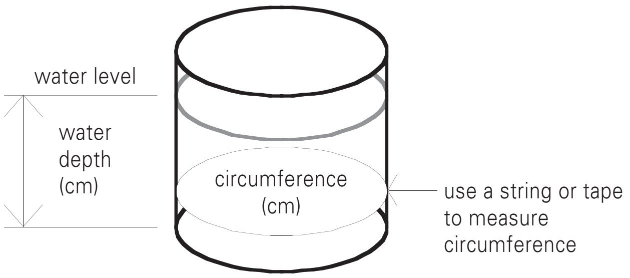
Volume (in litres) = π x diameter^2 (cm^2) x depth (cm) ÷ 4000

(π = 22÷7)

or use one of the following methods:



FORMULA 1: Volume (in litres) = 0.8 x water depth (cm) x diameter^2 (cm^2) ÷1000 (above diagram)



FORMULA 2: Volume (in litres) = 0.08 x water depth (cm) x circumference^2 (cm^2) ÷ 1000 (above diagram)

Only calculate the volume of water in the tank and not the volume of the tank.

B.

DETERMINING THE REQUIRED SIZE OF TANK TO BE INSTALLED

Maximum volume

The maximum amount of rainwater that can be collected can be calculated using the formula:

run-off (litres) = A x (rainfall – B) x roof area

'A' is the efficiency of collection and values of 0.8–0.85 (that is, 80–85% efficiency) have been used (Martin 1980).

'B' is the loss associated with absorption and wetting of surfaces and a value of 2 mm per month (24 mm per year) has been used (Martin 1980).

'Rainfall' should be expressed in mm and 'roof area' in square metres (m^2).

The maximum volumes of rainwater that can be collected from various areas of roof and at a range of average annual rainfalls are shown in Table B1. If the maximum volumes are less than the annual water demand, then either the catchment area will need to be increased or water demand will need to be reduced.

TABLE B.1: MAXIMUM VOLUMES OF WATER THAT CAN BE COLLECTED DEPENDING ON ROOF SIZE AND ANNUAL RAINFALL

MAXIMUM VOLUMES OF RAINWATER PER YEAR (KL)*							
Annual rainfall (A)	Roof area (m^2) (B)						
(mm)	**100**	**150**	**200**	**250**	**300**	**400**	**500**
150	10	15	20	25	30	40	50
200	13	21	27	35	42	53	70
250	18	27	36	45	54	72	90
300	22	33	44	55	66	88	110
400	30	45	60	75	90	120	150
500	38	57	76	95	114	152	191
600	46	69	92	115	138	184	230
800	62	93	124	155	186	248	310
1000	78	117	156	195	234	312	390
1200	94	141	188	235	282	377	470

* These volumes were calculated using a value of 0.8 for A and 24 mm for B.

Security of supply

Where a tank is to represent the sole source of supply, determining maximum volume is only a first step. The next step is to calculate the size of the tank needed to ensure the volume of water collected and stored in the tank will be sufficient to meet demand throughout the year, including during the drier months or through periods of low or no rainfall.

There are several mathematical models available for determining the size of tank needed to provide defined security of supply. In some cases, State government departments have used computer-based models to prepare tables of calculated tank size (see Section 7 Size of tanks).

The simplest way of checking a tank size estimated to provide water throughout an average year, is to use monthly rainfall data and to assume that at the start of the wetter months the tank is empty. The following formula should then be used for each month:

$V_t = V_{t-1} + (\text{Run-off} - \text{Demand})$

V_t = theoretical volume of water remaining in the tank at the end of the month.

V_{t-1} = volume of water left in the tank from the previous month.

Run-off should be calculated as discussed above (A = 0.8, B = 2 mm).

Starting with the tank empty then $V_{t-1} = 0$. If, after any month, V_t exceeds the volume of the tank, then water will be lost to overflow. If V_t is ever a negative figure then demand exceeds the available water. Providing the calculated annual run-off exceeds the annual water demand, V_t will only be negative if periodic overflows reduce the amount of water collected so it is less than the demand.

Tank size is not necessarily based on collecting total roof run-off. For example, from Table B1 the maximum water that can be collected from a roof area of 200 m^2, with an annual rainfall of 1000 mm, is about 156 kL. If the water demand is less than this, some overflow may occur while demand is still met. If water demand is to be met throughout the year, the tank should be large enough so that V_t is never negative.

Calculations should be repeated using various tank sizes until V_t is ≥ 0 at the end of every month. The greater the values of V_t over the whole year, the greater the security of meeting water demand when rainfalls are below average or when dry periods are longer than normal. The greater the security, the larger the size and cost of the tank.

TABLE B.2. TANK SIZES TO PROVIDE 99 PER CENT SECURITY OF SUPPLY

TANK SIZE (Kilolitres)*								
Volume required (L/day)	Annual rainfall (mm)	Roof area (m^2)						
		100	150	200	300	400	500	600
60	150					43		
	200				24			
	300		20	12	10			
	400	14	8	7				
	500	8	6	5				
	600	6	5	4				
	900	5	4	3				
100	200						40	–
	250				33	22		
	300				20	17		
	400			15	12			
	500		13	11	9			
	600	19	12	10	8			
	900	11	9	8				
	1200	10	8	7				
200	300							47
	350					40	29	26
	400					30	26	24
	500				28	24	22	20
	600			36	26	22	20	18
	900		29	23	18	16	14	
	1200	34	23	19	16	14		
400	500							51
	600							47
	700						49	44
	900					50	44	39
	1200				47	39	34	31

* The tank sizes shown were determined from summarised data provided by the South Australian Water Corporation and the Department of Water, Land and Biodiversity Conservation (SA). The original data were estimated using a computer simulation based on averaged rainfalls and rainfall patterns and using a value of 0.8 for A and 2 mm per month for B.

TABLE B.3: TANK SIZES TO PROVIDE 90 PER CENT SECURITY OF SUPPLY

TANK SIZE (KL)								
Volume required (L/day)	Annual rainfall (mm)	Roof area (m^2)						
		100	150	200	300	400	500	600
60	150				20	14		
	200			15	10			
	300	14	6	4				
	400	6	3	3				
	500	4						
	600	3	2					
100	150						34	27
	200				33	19	17	–
	300			16	10	8		
	400		10	8	6			
	500	11	6	5	4			
	600	8	5	4	3			
	900	6	4					
200	250						26	21
	300					29	20	17
	350				26	17	13	12
	400				19	14	11	10
	500			20	12	10	8	
	600		25	15	10	8	7	
	900	26	13	10	7			
	1200	18	10	8	6			
400	350							44
	500					42	30	24
	600					30	22	19
	700				39	27	21	18
	900				27	19	16	13
	1200			34	21	16	13	12

TANK SIZE (KL)								
Volume required (L/day)	Annual rainfall (mm)	Roof area (m^2)						
		100	150	200	300	400	500	600
600	500							
	600							
	700							47
	800						50	40
	900						43	34
	1200				50	37	28	24

* The tank sizes shown were determined from summarised data provided by the South Australian Water Corporation and the Department of Water, Land and Biodiversity Conservation (SA). The original data were estimated using a computer simulation based on averaged rainfalls and rainfall patterns and using a value of 0.8 for A and 2 mm per month for B.

TABLE B.4: WATER DEMANDS PER DAY, MONTH OR YEAR

WATER DEMAND (LITRES)		
PER DAY	PER MONTH	PER YEAR
60	1 830	21 960
100	3 050	36 500
150	4 575	54 800
200	6 100	73 000
300	9 150	109 500
400	12 200	146 000
500	15 250	182 500
600	18 300	219 600
800	20 500	292 000

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