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Bushfires and tank rainwater quality: A cause for concern?

Jean Spinks, Suzanne Phillips, Priscilla Robinson and Paul Van Buynder

ABSTRACT

In early 2003, after a prolonged drought period, extensive bushfires occurred in the east of Victoria affecting 1.5 million hectares of land. At the time, smoke and ash from bushfires, settling on roofs, contained pollutants that could potentially contaminate rainwater collected and stored in tanks for domestic use. The major concerns include polycyclic aromatic hydrocarbons (PAHs) from incomplete combustion of organic matter and arsenic from burnt copper chrome arsenate (CCA) treated wood. An increase in microbial contamination through altered nutrient levels was also hypothesised. A pilot study of 49 rainwater tank owners was undertaken in north-east Victoria. A rainwater tank sample was taken and analysed for a variety of parameters including organic compounds, microbiological indicators, metals, nutrients and physico-chemical parameters. A survey was administered concurrently. A number of results were outside the Australian Drinking Water Guideline (ADWG) values for metals and microbiological indicator organisms, but not for any tested organic compounds. PAHs and arsenic are unlikely to be elevated in rainwater tanks as a result of bushfires, but cadmium may be of concern.

Key words | arsenic, Australia, bushfires, cadmium, polycyclic aromatic hydrocarbons (PAHs), rainwater tanks

Jean Spinks
Suzanne Phillips
Environmental Health Unit, Department of Human Services,
17/120 Spencer Street,
Melbourne, VIC 3000,
Australia

Priscilla Robinson
School of Health Sciences,
LaTrobe University,
Bundoora, VIC 3083, Australia

Paul Van Buynder (corresponding author)
School of Population Health, University of Western Australia,
227 Stubbs Terrace, Shenton Park,
WA 6008, Australia
Ph: 08 93884971
Fax: 08 93884975
E-mail: *paul.vanbuynder@health.wa.gov.au*

INTRODUCTION

During the first two months of 2003, the regions of north-east Victoria and East Gippsland were subject to bushfires likened in severity to the 'Black Friday' fires of 1939 (CRC Catchment Hydrology, www.catchment.crc.org.au/bushfire/background_preamble.html, 2003). Over 1.5 million hectares were fire-affected and at least 41 houses and 200 other buildings were lost (DSE 2003). The fires coincided with one of the longest droughts on record.

During the fires, concerns were raised about the possible effect of smoke and ash contaminants on the quality of private drinking water supplies, particularly contaminants which settle on roofs and then are washed into storage tanks after rains or hosing of roofs to put out burning embers. Of particular concern was the possibility of polycyclic aromatic hydrocarbons (PAHs) from incomplete combustion of organic matter and arsenic from burnt copper chrome arsenate (CCA) treated wood.

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PAHs are a group of more than 100 compounds, including benz(a)anthracene and benzo(a)pyrene which are classified as probable human carcinogens by the International Agency for Research on Cancer (IARC 1973a,b). PAHs can be formed during the incomplete burning of materials such as wood, garbage, coal and gas and would be expected as a result of bushfires. They are also present in petroleum and coal based products, including roofing tar. PAHs can exist as vapours or attached to small solid particles such as dust, and can travel significant distances before settling on roofs and being washed into tanks after rainfall. Most PAHs are not readily soluble in water and break down over a period of weeks to months (ATSDR 1995).

Wood treated with CCA has been used in fence posts, furniture and other structures such as outdoor huts. When CCA treated wood is burnt, arsenic can be found in the resultant ash, much of which is in the water-soluble form (Dobbs & Grant 1976). This ash again may settle on roofs used as catchments for rainwater stored in tanks. Over time, exposure to arsenic by ingestion in both its organic and inorganic forms can result in a wide range of deleterious systemic health effects, including cancer (ATSDR 2000).

In addition to the above concerns, it was thought that an increase in burnt organic material being washed into tank water might lead to increased levels of microbial growth.

To review the extent of the bushfire related water quality issues, a pilot study was undertaken by the Public Health Division, Department of Human Services, Victoria. The aim of the study was to investigate whether contaminants from the bushfires had affected the quality of rainwater collected from roofs and stored in tanks for domestic use.

METHODS

Recruitment

Rural areas of north-east Victoria were selected as the study region based on fire severity data and an expected reliance on rainwater for a potable supply (Heyworth *et al.* 1998). Local maps were used to select properties (CFA 1998). Property numbers in the areas of interest were randomly selected and telephone numbers for these properties were acquired from local telephone directories. A telephone 'recruitment interview' was used to identify willing and eligible participants from the prepared lists. Eligibility criteria included the presence of an intact, undamaged, above ground water tank, and use of the water from this tank for drinking or food preparation. A total of 49 participants were recruited.

Survey

A survey was administered by a public health officer when the water tank was sampled. Information was collected on confounders such as tank construction materials and maintenance practices as well as estimates of the severity of smoke and ash contamination locally during the bushfires.

Rainwater tank testing

Water samples were collected and preserved in accordance with *Standard Methods* (1995). One complete sample set was taken from the household tap used to source drinking water. In the absence of a household tap connected to the water tank, the sample was taken directly from the tap on the tank where water was normally sourced. Five litres of water was discarded before the sample was collected. The parameters tested are shown in Table 1.

The water sample test results were communicated to each participant individually by mail, and a help line was established to provide further information if required by the participant regarding management of their private drinking water supply.

Table 1 | Parameters tested in water samples

Category	Indicator
Microbiological	*E. coli*, coliforms, faecal streptococci
Organic compounds	PAHs, including benzo(a)pyrene; VOCs including benzene, toluene, ethylbenzene, and xylene (BTEX); total organic carbon
Heavy metals	Lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), iron (Fe), zinc (Zn)
Physico-chemical	pH, colour (true and apparent), turbidity, total dissolved solids (tds), alkalinity
Nutrients	Total nitrogen (N), NH_3, nitrate, total phosphorus (P)

Data analysis

Data were analysed in Epi-Info software, Version 6.[1] After simple descriptive analyses, key independent variables were stratified into two or more levels. Microbiological quantifications were grouped into three levels and other parameters grouped above and below the Australian Drinking Water Guideline (ADWG). Mantel-Haenszel chi-square analyses at the 95% significance level were performed when more than two samples returned parameter results above the ADWG.

RESULTS AND DISCUSSION

The primary characteristics of the tanks sampled are shown in Table 2. Participants confirmed the presence of smoke; 48 participants reported the smoke on their property as being very bad (could not see more than 1 km into the distance) for an average of 7.1 days, and 45 participants reported the smoke as being bad (could not see more than 3 km into the distance) for an average of 18.6 days. Only two participants reported the smoke as being not bad.

Many participants were aware of the correct maintenance procedure for collecting and storing rainwater, but most did not adhere to these guidelines. None disinfected the rainwater in their tanks, and only nine respondents used some type of first flush or diversion system to divert potentially contaminated water away from their collection tanks.

The results of the rainwater tank samples are tabulated against the *Australian Drinking Water Guideline Standards* (ARMCANZ 1996) (ADWG) in Tables 3–6.

The physico-chemical results for the samples were found to be compliant with the ADWG, with the exception of pH. The range for pH was found to be 5.2–10.2 units. Of the samples tested, 31 tanks (63.3%) fell inside the recommended value of 6.5–8.5 units. The physico-chemical results did not indicate any demonstrable risk. The ADWG advise only extreme values, <4 or >11, may adversely affect health. In addition, values <6.5 may be corrosive and >8.5 may cause scale and taste problems. Values less than 8 may

[1]Centre for Disease Control and Prevention (CDC), USA, and World Health Organisation (WHO), Geneva, Switzerland: EpiInfo 6, a word processing, database and statistics program for public health, Version 6.04d, January 2001.

Table 2 | Characteristics of rainwater tanks

Total number of tanks sampled		**49**
Roof material*	Galvanised iron	26 (53%)
	Colourbond	20 (41%)
	Tiles	4 (8%)
	Zincalume	3 (6%)
Age of roof	Mean	21.2 years
	Median	16 years
	Range	3 mths–126 years
Tank material†	Concrete	35 (71%)
	Galvanised iron	7 (14%)
	Plastic	6 (12%)
	Fibreglass	3 (6%)
Gutter material‡	Colourbond	12 reports
	Galvanised iron	9 reports
	Zincalume	6 reports
	Painted metal	2 reports
	Aluminium	1 report
Age of tank‡	Mean	13.4 years
	Median	14.5 years
	Range	3 mths–30 years
Trees overhanging roof	Yes	12 (25%)
	No	37 (75%)
Solid fuel heater in home	Yes	41 (84%)
	No	8 (16%)
Disinfection agent used in water; e.g. chlorine	No	100%

*Four participants reported more than one material
†Participants could report more than one material due to interconnected tanks made of different materials
‡Not fully reported

Table 3 | Physico-chemical results

Parameter	ADWG*	Significance	Number of tanks outside ADWG*	Range*
Colour (filt), Pt/Co units	15 HU	Aesthetic	3 (6.1%)	<2–25 HU
pH, units	6.5–8.5	Aesthetic	18 (36.7%)	5.2–10.2 units
Total dissolved solids, 105°C	500 mg l^{-1}	Aesthetic	0	24–130 mg l^{-1}
Turbidity, NTU	5 NTU	Aesthetic	2 tanks had 5 NTU	<0.5–5 NTU

HU, Hazen units; NTU, nephelometric turbidity units; Pt/Co, platinum cobalt units

Table 4 | Heavy metal results

Parameter	ADWG*	Significance	Number of tanks outside ADWG*	Range*
Arsenic, as As (ICP-MS)	0.007	Health	0	<0.001–0.007
Cadmium, as Cd (ICP-MS)	0.002	Health	2 (4.1%)	<0.0002–0.0067
Chromium, as Cr (ICP-MS)	0.05	Health	0	<0.001–0.008
Copper, as Cu (ICP-MS)	2	Health	0	0.005–0.58
Iron, as Fe (ICP-MS)	0.3	Aesthetic	5 (10.2%)	<0.05–0.78
Lead, as Pb (ICP-MS)	0.01	Health	0	<0.001–0.006
Zinc, as Zn (ICP-MS)	3	Aesthetic	7(14.3%)	0.003–17

*Results in mg l^{-1}

Table 5 | Characteristics of tanks with elevated cadmium levels

Cd mg l^{-1} (0.002)*	Zn mg l^{-1} (3)*	pH units (6.5–8.5)*	Tank material	Tank age	Roof material	Roof age	Filter on tank	Fuel burning stove	First flush system	Smoke very bad	Smoke bad
0.0067	7.4	6.7	Plastic	1 year	Galvanised iron	50 years	No	Yes	No	7 days	14 days
0.0034	5.4	6.4	Fibreglass	25 years	Galvanised iron	50 years	No	No	No	6 days	28 days

*Australian Drinking Water Guideline

decrease the efficiency of chlorination; however none of the respondents was disinfecting their tank.

The results of the heavy metal testing are summarised in Table 4. Some cadmium, iron and zinc results were above the ADWG. Additionally one arsenic result was at the upper ADWG guideline level of 0.007 mg l^{-1} although below the World Health Organisation (WHO) guideline for arsenic in drinking water of 0.01 mg l^{-1} (WHO 2001). The next highest

Table 6 | Microbial testing results

Parameter	ADWG*	Significance	Result*	Percentage of tanks in range
Coliforms MPNColilert	0	Health	0	10.2
			1–99	49.0
			100–999	20.4
			1000 +	20.4
E. coli MPNColilert	0	Health	0	67.3
			1–99	32.7
Faecal streptococci	0	Health	0	26.5
			1–99	59.2
			100–999	12.2
			1000 +	2.0

*Results in organisms per 100 ml

arsenic value recorded was 0.003 mg l^{-1}, and the majority of results (41 tanks, 83.7%) recorded values that fell below detectable levels (< 0.001 mg l^{-1}). It is unclear if the arsenic result that fell on the upper guideline value was due to air contamination from the bushfires, or some other source. The property in question was subject to significant air pollution during the fires (10 days of visibility less than 1 km into the distance, followed by 14 days of visibility less than 3 km into the distance), and the owners did hose down the roof during the bushfires with water obtained from the reticulated supply; however no obvious CCA treated structures burnt in the near vicinity. As the 'maximum tolerable daily intake value for arsenic includes adequate safety factors' (ADWG 1996) this result is not considered to pose any health risk. The overall arsenic levels suggest that the contamination of collected rainwater by arsenic from CCA treated wood during bushfires is not likely.

Two cadmium samples results were above the ADWG health guideline of 0.002 mg l^{-1} (0.0067 mg l^{-1}, 0.0034 mg l^{-1}), and one value (0.0018 mg l^{-1}) was just below. The next highest value recorded was 0.0005 mg l^{-1} and the majority of results (39 tanks, 80.0%) fell below detectable levels (< 0.0002 mg l^{-1}).

Long-term exposure to cadmium can cause kidney dysfunction and osteomalacia (ADWG 1996). Bushfires can release some cadmium into the air (ATSDR 1999). Cadmium is also found naturally in water, and elevated levels may result from industrial or agricultural contamination or from impurities in galvanised (zinc) fittings, solders or brasses (ADWG 1996). Cadmium metal is used as an anti-corrosive coating for steel.

The characteristics of the collection systems for the two properties with elevated cadmium are shown in Table 5. In both, the results for zinc were also above the ADWG, the catchment roof was made of galvanised iron, and was over 50 years old. This may indicate that the corrosion of the roof was the source of both the cadmium and zinc in the samples. While contamination from bushfire smoke and ash may have contributed to the elevated cadmium levels found in the samples, the smoke exposure described at these two properties was similar to overall averages. Further investigation is warranted and repeat sampling is planned later in the year.

The ADWG for iron, 0.3 mg l^{-1}, is a taste threshold and an aesthetic guideline only. Five samples were found to have levels of iron above this value, the highest of which was 0.78 mg l^{-1}. Iron occurs naturally in water, usually at <1 mg l^{-1} (ADWG 1996) and the levels of iron recorded were not considered to be a health risk. No relationship was found in the study between iron levels greater than the ADWG and galvanised iron tanks or roof materials.

The ADWG for zinc is 3 mg l^{-1} and is an aesthetic guideline only. Seven samples were found to contain zinc levels higher than this value, the highest of which was 7.4 mg l^{-1}. Elevated zinc levels may result from the corrosion of galvanised iron roof or tank material, or galvanised pipes and fittings, leading to taste concerns. A significant association was found between having a galvanised iron tank and a zinc level above the ADWG (RR 3.33, 1.03–10.78, $p = 0.0002$). Similarly, the association between having a galvanised iron roof and an elevated zinc level was almost significant (RR 3.67, 0.58–23.03, $p = 0.06$). Conversely, concrete tanks were associated with having zinc levels below the ADWG (RR 0.30, 0.14–0.63, $p = 0.02$).

Although five samples returned iron levels above the ADWG, and seven samples returned zinc levels above the ADWG, the presence of both these metals has been associated with roof and tank materials in previous studies (Thomas & Greene 1993; Banister *et al.* 1997) and it is thought unlikely that the elevated results are associated with the bushfires.

The nutrient results were unremarkable. The ADWG for nitrate is 50 mg l^{-1} which will protect bottle-fed infants under 3 months from methaemoglobinaemia. None of the sample results was outside this guideline value. Apart from nitrogen and nitrate there are no specified ADWG levels for nutrient levels in drinking water. Higher nutrient levels are not a stand-alone health risk, and may promote the growth of microbiological contamination but nutrient levels were not elevated in these samples.

All the samples returned results for benzo(a)pyrene, benzene, toluene, ethylbenzene and xylene that were below the detectable level of 1 μg l^{-1}. Additionally, all total polyaromatic hydrocarbons results were below the detectable level of 8 μg l^{-1}.

Concern had been expressed that organic compounds such as PAHs and volatile organic compounds (VOCs) would be found at higher than expected levels in rainwater tank samples after the fires but this was not demonstrable in this study. The possible reasons for this include that the compounds were not found owing to the timing of the testing in relation to rain events (either too early or too late), the sample size was not big enough to detect samples with elevated levels of these compounds or the areas chosen for the study were not representative of other areas affected by bushfires. It is likely however that the hypothesis that these compounds may be washed into tanks was unfounded.

Testing of nearby water from catchments in the same geographical location was conducted both before and after the first significant post-bushfire rainfall recorded in the area. Polycyclic aromatic hydrocarbons were not found at elevated levels (Department of Human Services, Victoria, unpublished results) in these waterways either.

The results of microbiological indicator testing are summarised in Table 6. No significant relationship was found between the levels of microbiological indicator organisms found in the samples and the maintenance procedures of using a first flush system, cleaning the gutters or cleaning the holding tank. A high percentage of samples tested had significant levels of microbiological indicator organisms. The presence of *E. coli* and faecal streptococci may be indicators of faecal contamination and a potential health risk.

Many studies have shown significant microbiological contamination in rainwater stored in tanks for domestic use has (Appan 1997; Banister *et al.* 1997; Verrinder & Keleher 2001). Microbiological contamination may be a result of many factors including animal droppings on the catchment roof, dead animals and insects or organic material on the roof or in gutters, soil, agricultural or industrial waste or human sewage being washed into tanks. The level of microbiological contamination found in a rainwater tank sample is the result of a complex and dynamic set of parameters. Factors involved include physico-chemical properties of the water such as dissolved oxygen, pH and temperature, and the typ
e of tank, roof and guttering materials used to catch and store rainwater. Overhanging trees, treatment of roofs, ash from solid fuel burning stoves, dust, moss and lichen on roofs and gutters, pesticides and other agricultural waste can also contribute.

The microbiological results of studies conducted in Victoria and South Australia when air contamination from bushfires

Table 7 | Microbiological contamination in the samples in comparison with previous Australian tank water studies

Study	No. of tanks in study	Positive for faecal coliforms/ *E. coli*	Positive for faecal streptococci	Positive for coliforms
Fuller *et al.* 1991	41	20% (tanks)	26% (samples)	No data
South Australia 1981				
Lightbody 1993	60	18% (samples)	82% (samples)	71% (samples)
Victoria 1993				
Bannister *et al.* 1997	20	28%	No data	57%
Victoria 1997				
Verrinder & Keleher 2001	100	38%	No data	52%
Victoria 2001				
This study	49	32%	73%	90%
Victoria 2003				

was not a consideration are summarised in Table 7. The results of this study did not vary greatly from previous studies.

It was hypothesised that ash, embers and burnt organic material from the bushfires would increase the turbidity thus reducing disinfection effect and increase nutrient levels. Although we cannot exclude air contamination from the bushfires as a contributor to the number of indicator organisms found in the samples, the results are not dissimilar to previous work.

The presence of indicator organisms in rainwater stored in tanks is not necessarily indicative of pathogens being present. Verrinder & Keleher (2001) report that 'exceeding the numerical guidelines for the microbiological content might not necessarily be a threat to the health of the public'. In part this may be due to enhanced immunity in a population regularly exposed to this water source. Participants in this study were offered advice on tank water maintenance and disinfection procedures.

CONCLUSION

The aim of this study was to explore possible deleterious effects of bushfires on the quality of rainwater captured from roofs and stored in tanks for private supply. Of greatest concern was the possibility of polycyclic aromatic hydrocarbons (PAHs) from burnt organic matter and arsenic from burnt treated pine in the form of ash being washed into storage tanks from roofs. None of these parameters fell outside the ADWG, and even allowing for the small number of tanks in this study, it is unlikely that these compounds pose a threat to public health via water following bushfires.

As with previous studies iron and zinc were found in some samples at levels above those of the ADWG and this is thought to be related to tank and roof materials. It is likely that the elevated cadmium levels were also related to tank or roof materials; however as cadmium is released into the air during bushfires, contamination from this source cannot be ruled out.

Elevated levels of microbiological indicator organisms were found in a significant portion of the samples tested confirming previous Australian studies. Given the similarity with previous studies and the poor levels of tank maintenance described by the respondents, these results are probably not due to the effects of the bushfires, although it cannot be ruled out as a contributing factor.

As a significant rainfall event occurred before the collection of baseline samples, the results were compared with the

ADWG alone. A study comparing the parameters of rainwater in the same tanks before and after bushfires would provide a more meaningful comparison, as a large number of confounding factors can cause samples to fall outside the ADWG.

The small sample size (49), has limited the generalisability of the study results; however, the health risk associated with drinking rainwater stored in tanks following bushfires appears to be low. Further investigation of how best to communicate maintenance procedures for private drinking water supplies to the public remains a public health priority. In addition, as a precautionary measure, the recommendation is to use first-flush or diversion systems for tanks especially following times of significant air pollution such as during and following bushfires.

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