

Lead and other heavy metals: common contaminants of rainwater tanks in Melbourne

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Abstract

In a series of investigations, we found that rainwater tanks in Melbourne are commonly contaminated with lead and other heavy metals at levels that exceed drinking water guidelines. An investigation of six pilot roofs (glazed tiles, pre-painted steel and 55% aluminium- zinc coated roofs with and without lead flashing) and tanks revealed that lead flashing significantly contributed to the lead content in tank water which was up to 50 times the recommended Australian Drinking Water Guidelines (ADWG) limits. Similar results were found in two further studies of full scale tanks, where 33% of the 49 tanks contained lead concentrations in tank water exceeding the recommended limits, being up to 35 times ADWG values. Concentrations of aluminium, cadmium, iron and zinc were also found at levels exceeding acceptable health and aesthetic levels. No relationship has been established yet between poor water quality and roof, gutter or tank materials or location of the sub-urban rainwater tanks. It is concluded that metals concentrations and lead concentration particularly, is an important issue which must be addressed in the task of finding alternative water sources for Australian cities.

1. INTRODUCTION

Rainwater tanks are increasingly used in Australian urban areas because they are viewed as a household scale alternative water source that can help in the effort to address the impact of water scarcity. In the state of Victoria, Australia, government incentives and regulation were introduced in July 2005 to encourage the installation of tanks in new developments. The introduction of water restrictions also led to an increase in tank installation and use in existing houses (i.e. retrofit). The majority of rainwater tanks in urban Australia supply water for non-potable uses, such as for garden watering and toilet flushing. Increasingly though, this water is being used to supply end uses which involve human contact.

Recent statistics show that the state of New South Wales has the highest number of tanks installed (329,900), followed by Victoria (305,400) and South Australia (305,000) (ABS, 2004). In South Australia, there are reports of 48% of households having a rainwater tank. South Australia also reports the highest dissatisfaction with the quality of reticulated water supply. Thus, potentially, a high number of people could source their water from the rainwater tanks rather than from the reticulated supply. The use of rain tanks at household scale means that the tank maintenance, and more importantly, the quality of water supplied from the tank is the householders' responsibility rather than that of a water authority.

The increasing use of rainwater tanks has led to increased interest in the quality of the water that they supply. The occurrence of microbial pollutants in the urban rainwater tanks has been considered in many studies because it poses an acute health risk. In comparison, the occurrence of heavy metals in the urban tanks has been of lesser interest perhaps because they do not have an immediate health effect. However, the few studies that have been undertaken (Coombes et al., 2000; Simmons et al., 2001; Thomas and Greene, 1993) have all found heavy metals at the outlet tap at concentrations higher than acceptable levels. Identifying the source of metals in the rainwater tanks has been the focus of other studies: proximity of roofs to traffic (Adachi and Kobayashi, 1992; Yaziz et al., 1989) or

to industrial areas (Thomas and Greene, 1993) and the level of urbanization (Fuchs et al., 1997) were considered to be the main cause of high lead concentrations in the tank water.

Recent guidelines on use of rainwater tanks (enHealth Council, 2004) suggest that the introduction of unleaded petrol, the reduction of lead concentrations in paint and development of standards for materials to be used for rainwater harvesting were expected to reduce the potential for rainwater tank lead contamination. In addition, Sinclair et al. (2005) stated that based on a literature review, the level of metal contamination in rainwater tanks is unlikely to exceed the Australian Drinking Water Guidelines (ADWG) values, except when there is a major source of industrial pollution located nearby. These conclusions about lead concentration in rainwater tanks are consistent with the results of stream monitoring, which suggest a decrease in environmental contamination by lead since the introduction of the above mentioned measures (Alexander and Smith, 1988).

However, recent research (Magyar et al., submitted-a; Magyar et al., in press) has found that even when sampling a few days after a rain event with near full water level in the tank, water collected from the tank outlets contained heavy metals, including lead, exceeding ADWG levels (NHMRC & NRMCC, 2004) and Recreational or Irrigation Guidelines (ANZECC and ARMCANZ, 2000). One of these studies investigated pilot tanks situated in a residential area in Melbourne's south east (Magyar et al., submitted-a), while the other study investigated full size tanks all located in Melbourne's north (Magyar et al., in press). Therefore it appears that heavy metal, and particularly lead contamination of rainwater tanks, is widespread. The current paper presents the findings of a series of investigations of pilot and actual urban tanks throughout a wider Melbourne metropolitan region.

2. METHODOLOGY

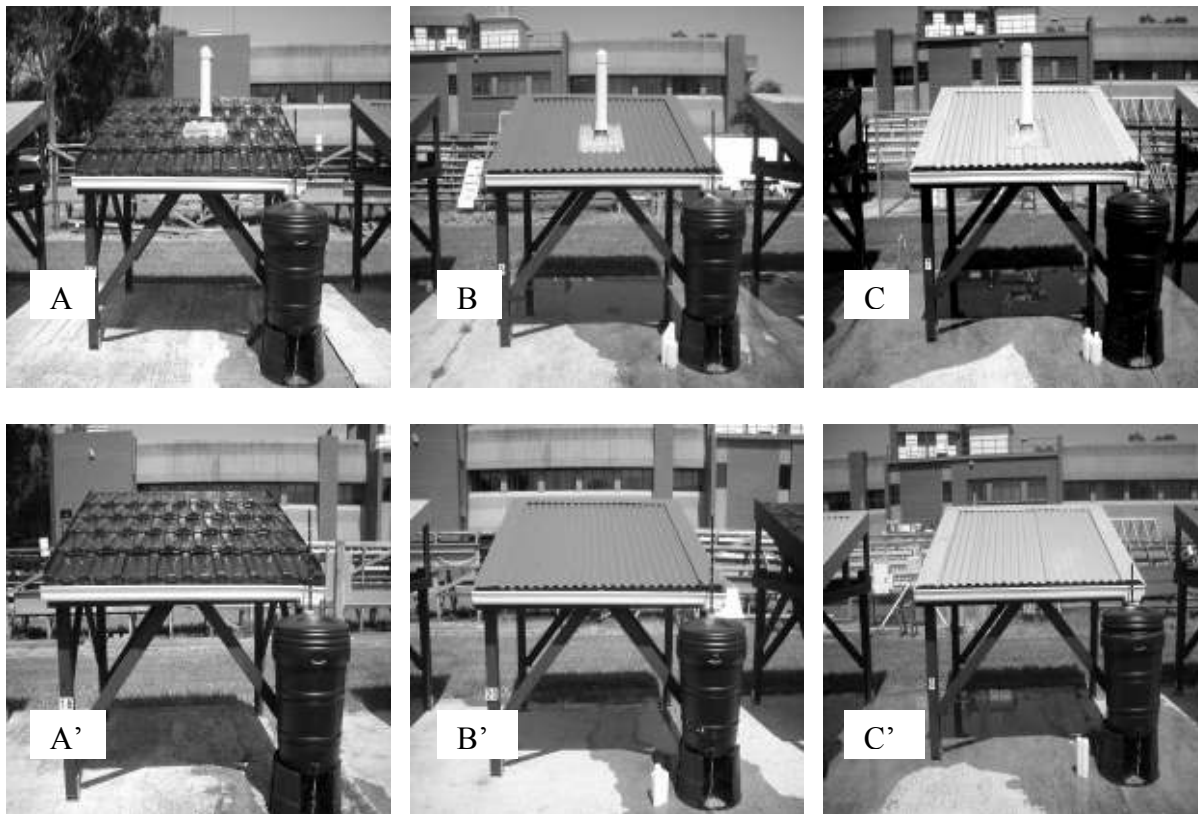
A pilot study (Study 1) investigated water quality in six pilot tanks collecting water from trial roofs. The study helped understanding how roof materials influence water quality in the tanks, but had the disadvantage that water from the pilot tanks was not in use. To verify the findings of Study 1, it was decided to investigate nine full size household tanks collecting water from various roof materials (Study 2). Since the results from Study 2 showed high concentrations of lead and other heavy metals in the tank water and tanks sediments, the investigation into rainwater tank quality was extended to a wider Melbourne metropolitan region involving a further 40 tanks (Study 3).

2.1. Study 1- Six pilot tanks and trial roofs

Six pilot tanks collecting water from trial roofs were monitored for a period of nine months. The trial roofs and tanks were located in Highett, Victoria, Australia, and were installed in October 2004 using construction materials generally used in the building industry in Australia. The roof materials were glazed tiles, pre-painted steel (PPS) and 55% aluminium-zinc coated (ZnAl) roofs with and without lead flashing, therefore giving six combinations of materials. The roofs were installed within 1.5 m proximity to each other and with no evident sources of pollution (i.e trees) in their vicinity. The relative sizes of the trial roofs (3.7 m²) and tanks (0.1 m³) were scaled to be representative of a typical urban scenario, i.e. a 2.7 m³ tank collecting rainwater from a 100 m² roof catchment. Samples were taken on a quarterly basis, two to six days after a rain event. The water samples were analysed for concentrations of Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn by NATA approved laboratories. The samples were digested as per standard methods (APHA/AWWA/WEF, 1995) with an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). The pH of water was also measured on site with a W-22XD series Horiba multi-probe instrument which was calibrated prior to each measurement. Further details of the project can be found in Magyar et. al (submitted-a).

Table 1: Characteristics of roofs and tanks in Study 1

Roof material	Roof area, m ²	Lead flashing area, m ²
Glazed tile with lead flashing (Figure 1 A)	3.67	0.24
Glazed tile (Figure 1 A')	3.72	0
Pre-painted steel with lead flashing (PPS) (Figure 1 B)	3.76	0.24
Pre-painted steel (PPS) (Figure 1 B')	3.77	0
55% Aluminium-Zinc coated steel with lead flashing (ZnAl) (Figure 1 C)	3.72	0.24
55% Aluminium-Zinc coated steel (ZnAl) (Figure 1 C')	3.75	0

**Figure 1: Study 1: trial roofs and tanks**

2.2. Study 2- Nine urban tanks

Another study investigated nine full size tanks collecting water from various roofs materials. All tanks were retrofitted to existing houses, such that they were between 4 months to 20 years old. Eight of the tanks were situated in suburbs north of Melbourne (East Brunswick / Northcote) and the other tank is situated in the south-eastern area (Doveton) (Figure 2). The water samples were taken two to seven days after a rain event from the tap which was positioned close to the base of the tank (30-150mm from the tank's base) while the tanks were full of water. The water samples were analysed for concentrations of Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn by NATA accredited laboratories. The samples were prepared for metals analysis as per standard methods (APHA/AWWA/WEF, 1995) and analysed with an ICP-OES. The pH of water was also measured on site with a W-22XD series Horiba multi-probe instrument which was calibrated prior to each measurement. Further details of the project can be found in Magyar et. al (in press).

Table 2: Characteristics of roofs and tanks in Study 2

Roof materials	# of roofs	Tank size range (m ³)	Range of outlet height from base (mm)	Tank age (years)	Maintenance
Tiles	3	0.23-23	30-150	0.3-20	Once a year to very rarely
PPS	1				
PVC	1				
ZnAl	1				
GI	2				
PT,PPS,ZnAl	1				

PPS-Pre-painted steel or Colourbond[®]; ZnAl-Aluminium-Zinc coated steel or Zinalume[®]; GI-Galvanised iron; PT- painted tiles.

2.3. Study 3- 40 urban tanks in metropolitan Melbourne

An additional study investigated 40 tanks located within metropolitan Melbourne (Figure 2). Owners of the tanks were provided with a questionnaire, an acid rinsed bottle and instructions on how to sample from the tank's tap supply point. Sampling took place between May to September 2006. The samples were taken one to two days after a rain event from a supply point (tanks' tap) before a pump (if a pump was in use), to avoid any contamination with metals from the pump. The owners completed the survey which included questions about the tank and roofs characteristics, installation date, visible contamination on the roofs and gutters, uses of water and maintenance regimes. Further details of the project can be found in Magyar et al (submitted-b).

All the samples were taken to a NATA accredited laboratory where HNO₃ was added for sample preservation and then were stored in a refrigerator at approximately 4°C, as per method 3010B (APHA/AWWA/WEF, 1995) until a batch of around 15 samples was collected and analysed.

The water samples were analysed for concentrations of Al, As, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, K, Na, Se, Sn and Zn. The water quality analyses were performed according to Standard Methods 3030D and 3120B by using the ICP-OES method. For each batch of samples, blank tests, duplicates, standard reference materials (SRMs) for trace metals and known additions recovery (spikes) were used to determine bias (APHA/AWWA/WEF, 1995). All duplicates and spikes and reference materials were found in line with acceptable limits (of 90-110%, 80-120% and the acceptance limits defined by the laboratory's SRMs certificates respectively).

As there are no specific guidelines for water quality from rainwater tanks, and the tanks under investigation were used for various end uses, including drinking, the Australian Drinking Water Guidelines (ADWG) (NHMRC & NRMCC, 2004) were used as reference. Additional guidelines used for comparison were Recreational Water Guidelines (RWG) which include primary contact such as swimming and bathing and Agricultural Irrigation Guidelines (AIG)(ANZECC and ARMCANZ, 2000).

Characteristics of the roofs and tanks in Study 3 are presented in Table 3 and the location of tanks investigated in Study 2 and Study 3 is presented in Figure 2.

Table 3: Characteristics of roofs and tanks in Study 3

Roof materials	# of roofs	Tank size range, m ³	Tank age, years	Outlet height from base (mm)	Maintenance of roofs, gutters and tanks
Tiles	12	1-45	1-27	50-400	2 weeks to never
PPS	9	1-31.7	1-6	10-100	3 monthly to never
GI or ZnAl	8	0.75-9	1-16	20-100	3 monthly to never
Plastic	4	0.2-13	2-11	35-50	2weekly to never
Combination	7	0.5-9	1-6	45-400	3 monthly to never

Combination: includes roofs made of pre-painted steel or Colourbond[®], 55% -Aluminium-Zinc coated steel or Zinalume[®], galvanised iron, tiles, painted tiles.

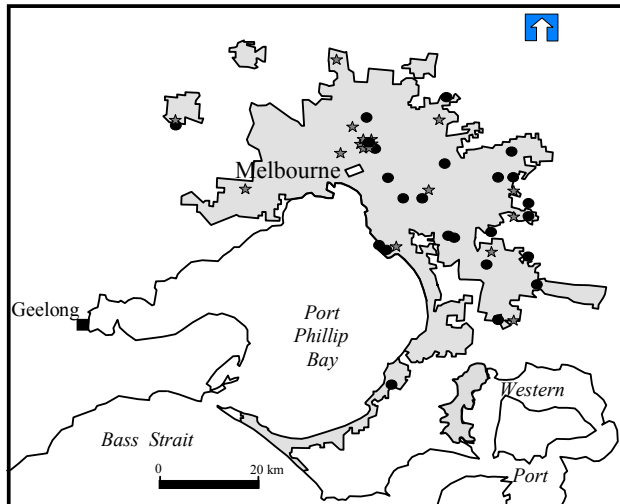


Figure 2: Location of rainwater tanks in metropolitan Melbourne (grey shaded area); ☆ - tanks with Pb levels exceeding ADWG; ● - tanks with Pb levels within ADWG

3. RESULTS

3.1. Study 1

Tank water from the glazed tile roof was found with concentrations of Pb, Cr and Ni exceeding the ADWG health values, being 0.04 mg/L, 0.1 mg/L and 0.17 mg/L respectively. It also contained concentrations of Fe and Mn exceeding the aesthetic ADWG values, being 2.1 mg/L and 0.17 mg/L respectively. Water collected from the 55% aluminium-zinc coated steel (ZnAl) and pre-painted steel (PPS) roofs had metal concentrations that stayed within guidelines for the whole period of investigation.

The rainwater collected from all three roofs with lead flashing contained Pb concentrations exceeding the ADWG (and WHO) maximum recommended values. The pre-painted steel roof with lead flashing gave the highest concentration of Pb in the tank water, up to 50 times greater than the guideline recommended values. The 55% aluminium-zinc coated steel roof with lead flashing gave a Pb concentration of up to 0.42 mg/L, whereas the glazed tile roof with lead flashing produced the lowest concentration, although it was still up to 29 times over the recommended ADWG value (0.01 mg/L).

The large difference in Pb concentration in rainwater collected from roofs with and without Pb flashing, showed that the lead flashing alone contributed significantly (up to 99%) to the Pb content in tank water (Figures 3a and 3b).

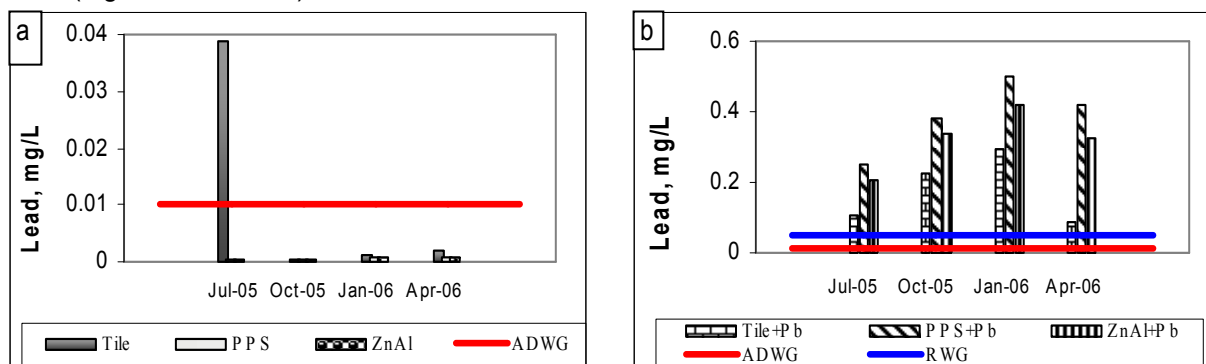


Figure 3: Lead concentration in the pilot tanks. a- Pb concentration in tank water from roofs without Pb flashing; b- Pb concentration in tank water from roofs with Pb flashing

The pH was found to be acidic in all the samples, ranging from 4.7 to 5.6. This is well below the recommended ADWG range of 6.5-8.5 and can cause corrosion of downstream metal fittings and plumbing.

3.2. Study 2

The concentrations of Al, Cd, Fe and Zn exceeded the ADWG (2004) acceptable levels in at least one tank. The concentration of lead exceeded the ADWG in five out of the nine tanks investigated (Figure 4b, log scale graph). In one of the tanks (F7), the concentration of Pb was 35 times higher than the ADWG recommended value of 0.01 mg/L and 7 times more than the RWG acceptable level of 0.05 mg/L, making the water from this tank unacceptable for drinking or recreational purposes.

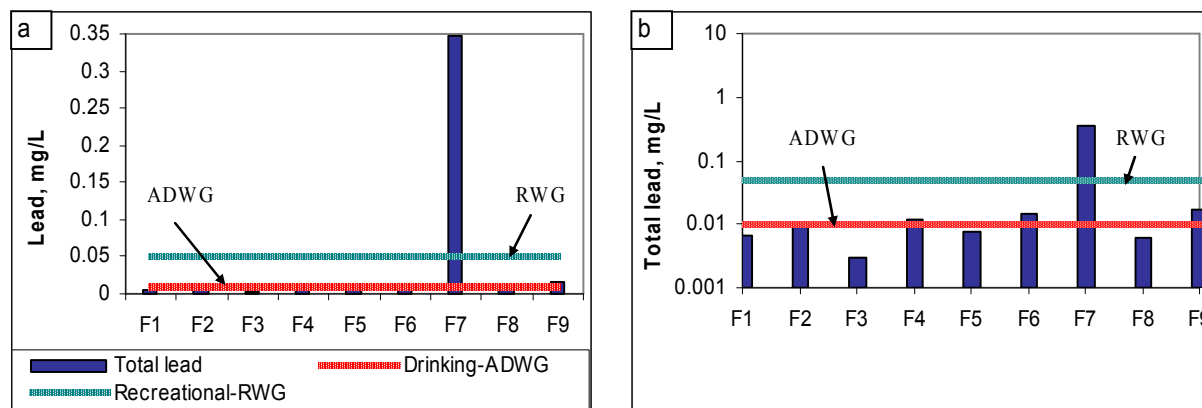


Figure 4: Lead concentration on the field tanks. a- Pb concentration in tank water; b- log scale presentation of graph a

Analysis of pH measured in the nine tanks ranged between 4.3 and 4.9. This is well below the recommended values of 6.5 (NHMRC & NRMCC, 2004), therefore it would be corrosive to metal faucets and fittings used in the distribution of this water and it would also cause the leaching of metals from the sediment layer at the base of the tank.

3.3. Study 3

The survey of rainwater tanks across Melbourne metropolitan area identified that most of the tanks have been installed during this decade. Only two tanks had first flush diverters installed. Out of the 40 rainwater systems investigated, 42% had gutters and roofs cleaned at least once a year, but the tanks and sediment in the tanks had never been cleaned out. There were reports of six tanks (15%) having an odour and reports of brown or yellow water colouration for 15 tanks (38%).

A total of 11 tanks (28%) were found with Pb concentrations exceeding ADWG (NHMRC & NRMCC, 2004) recommended value of 0.01 mg/L. Two of those 11 tanks had Pb concentrations at levels exceeding the RWG (ANZECC and ARMCANZ, 2000) recommended value of 0.05 mg/L as well.

Five of the tanks (13%) were reported as being the only water source to the house therefore they used water for indoor uses, including drinking. Another three water tanks were used for occasional drinking although the houses had reticulated water supply. Other indoor reported uses of rainwater were for the washing machine and toilet flushing. One of the tanks being the only source of water to the property had Pb levels as high as 20 times the ADWG and four times the RWG levels.

A summary of the findings in Study 2 and Study 3, for the 49 full scale rainwater tanks, is presented in Table 4 below.

Table 4: Tanks with metals exceeding relevant guideline values

Constituent	# of samples with metal content above ADWG	% of tanks with metal content above ADWG	Range of values which exceed ADWG (mg/L)	# of samples with metal content above RWG	# of samples with metal content above AIG	
Aluminium	2	4	0.22-0.62	2		
Cadmium	1	2	0.004			
Copper		0			2	
Iron	4	8	0.5-0.99	3	7	
Lead	16	33	0.011-0.35	3		
Zinc	5	10	3.12-11.15	3	2	3

Aluminium and cadmium can be an impurity in zinc galvanised iron roofs and therefore found in collected tank rainwater (Van Metre and Mahler, 2003). Indeed, in Study 2, the tank with high concentration of Cd collected water from a galvanised iron roof.

As stated before, previous studies suggest that the causes of elevated lead levels in tank water are proximity to traffic or to industrial areas. However, these were not found to be important explanatory variables in this study. The lead may have come from flashing on the roofs (Magyar et al., submitted-a; Simmons et al., 2000; Van Metre and Mahler, 2003). Several tank owners were contacted about the presence of lead flashing on their roofs, but most of them could not identify lead flashing from other materials. Therefore, there was insufficiently reliable information collected to allow us to draw any firm conclusions. Future research is planned to attempt to identify the lead sources.

Previous studies suggested that the source of zinc in rainwater tanks is from galvanised iron roofs (Gromaire et al., 2001). Indeed, out of the seven tanks with zinc levels above relevant guidelines, five collected water from galvanised iron roofs.

In most of the samples, arsenic, selenium and tin were below the ICP detection limits. All other metals and metalloids (Cr, Mn, Ni and Ca, K, Mg, Na, Mg) were detected in the 40 tanks, all within acceptable guideline levels.

4. DISCUSSION

Six metals out of the 16 elements analysed in the water samples from suburban rainwater tanks were found in concentrations exceeding various standards. High concentrations of Al, Cd, Fe, and Zn can lead to aesthetic problems if water is used indoors, such as discolouration of clothes and household appliances. Concentrations of Cu and Zn exceeding the acceptable levels for irrigation can potentially have a toxic effect on plants when used for irrigation. Cadmium was found to exceed the ADWG in one of the tanks (although it was not used for drinking water supply) and there are no known side effects for skin contact. The concentrations of Pb, however, were found to be at levels of concern for human health.

It is important to note that 46 out of the 49 rainwater tanks (from Study 2 and Study 3) were retrofitted to established houses in the current decade, by property owners. It is likely that suitability of collection systems (i.e. roofs and gutter materials), tank components, and design has not been professionally assessed, as would be the case when a rainwater tank is being installed as part of a new residential development. In the case of lead, new building regulations clearly state that due to its toxicity, lead material should be avoided for rainwater goods including roofs collecting rainwater (AS/NZS 3500.3, 2003).

Measures implemented in the current decade, such as the introduction of unleaded petrol, the reduction of lead concentrations in paint and development of standards for materials to be used for rainwater harvesting, were expected to reduce the potential for rainwater tank contamination. Analysis of the location of those 16 tanks with high lead concentrations revealed that they were all positioned in

suburban areas of Melbourne, none of them being obviously more close to heavy industry than others. Those tanks were not considered any more close to traffic than the tanks that did not present high levels of lead in the water, which does not support the results of Yaziz et al (1989) and Thomas and Greene (1993). Unfortunately, there was not enough information about the presence of any lead flashing on the roofs collecting the water, to confirm if this was a major contributing factor.

This study found lead concentrations comparable with previous findings for urban and industrial areas, with a third of the tanks having high lead levels. Variation in rainwater tank components and roof materials could explain variation in water quality results. The survey showed that approximately 40% of the roofs received modest levels of maintenance. In comparison, most tanks (87%) received no maintenance, which is expected to have contributed to high contents of metals in the tank water.

It is important to note that at the same time as we have been finding lead levels in rain tank water that exceed drinking water guidelines, 'safe' blood lead levels are continuing to be revised downward with low-level environmental exposure to lead now seen as a significant health issue (Nawrot and Staessen, 2006). It is highly undesirable that the increased use of rainwater tanks in our urban environments, primarily motivated by water scarcity, has the unintended consequence of increasing individuals' exposure to this heavy metal.

5. CONCLUSION

The two studies of full scale urban tanks (Study 2 and Study 3) summarized in this paper revealed that water supplied from 33% of the residential rainwater tanks in the metropolitan Melbourne contained high concentrations of lead. The maximum concentration of lead measured in a full size suburban tank was 35 times more than the acceptable ADWG recommended level.

The use of this water could pose a health and/or an environmental risk, especially in regards to the high concentrations of lead. These risks need to be addressed if rainwater tanks are to provide an alternative water source for cities in Australia.

This study had insufficient information to be able to identify a relationship between poor water quality and roof, gutter or tank materials, or location of roof and tank in the urban context. Further research into the role of lead flashing, water level at the time of sampling and the volume of sediments in the tank is required to identify the causes of high concentrations of lead in tank water.

Nevertheless, the reported modest levels of roof maintenance and absence of tank maintenance is thought to have contributed to poor water quality in the tank. Therefore, regular cleaning of the tank is recommended, in addition to the periodic cleaning of roofs and gutters.

6. ACKNOWLEDGMENTS

The project's industry partner, CSIRO Water for a Healthy Country is gratefully acknowledged for financial support. The individual field tank volunteers are also gratefully acknowledged for participating in this study.

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