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Chemical Water Quality and Health Risk Assessment of Urban Rainwater Tanks

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Abstract

There has been strong interest in recent years to use rainwater tanks in urban areas of Australia, as catchments yields become less predictable and urban populations continue to increase. The CRC Water Quality and Treatment is conducting research to assess the quality of water from rainwater tanks in urban and industrial areas of Australia. The aim of this research is to concentrate on tanks where a potable supply exists and to use the data in health risk assessment. Storm event data has shown that discarding the first millimeter of runoff via a first flush device usually does little to substantially reduce the mean concentration of contaminants. First flush devices can also substantially reduce the catch of rainwater tanks. Rain sampling shows that there is some lead in rain, though there may be a greater input from the roof itself. The use of rainwater in hotwater systems (HWS) can lead to increases in copper and lead concentrations. The lead concentration from hot water sometimes exceeds the drinking water guidelines. As such, where the HWS is supplied from a rainwater tank, drinking or the use of hot water for cooking is not recommended. The source of the lead from the roof requires further study.

INTRODUCTION

A literature review conducted during by the CRC WQT in 2002 found there was little data on rainwater tank water quality from studies conducted in Australia in urban and industrial areas. It also found that it was not possible to extrapolate from the overseas literature for the Australian situation because each study was significantly influenced by local conditions and the constraints of the specific study methodology (Sinclair et al, 2004). There were very few intensive reports anywhere reviewing the quality of rainwater verses the allowable end uses for rainwater. This identified a large gap in understanding of water quality characteristics in rainwater tanks located in urban and industrial areas in Australia, particularly from a physico-chemical and human health perspective. There was sufficient evidence in the literature that microbial water quality would not always meet the ADWG (Sinclair et al, 2004). Therefore effort towards understanding and controlling pathogens has been to look into critical control points as a mean of improving microbial water quality. Results from research on pathogens will be reported elsewhere. Critical control points include hot-water systems and UV treatment as a means of disinfection. First flush devices were identified as a potential method of improving both microbial and chemical water quality.

Recommendations from a literature review conducted as part of this study, were that investigation was needed into aesthetic and chemical quality – including monitoring for health related parameters include lead, copper and benzo-(α)-pyrene. It was considered that tests for lead and copper (depending on the analysis method) may also have yielded information on other metals although these were unlikely to be present at problematic levels. Non-health related parameters monitored included pH, turbidity and zinc. In addition to characterising water quality from rainwater tanks, the review recommended comparing the effect of a number of factors such as the presence or

absence of first flush devices, different roof materials, different tank materials, different point of use devices and atmospheric deposition.

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

METHODS

National reconnaissance

A reconnaissance of water quality data from around Australia was conducted aimed at obtaining a snapshot of the types and concentrations of chemical contaminants in various locations and climates, on which to base future research. Six tanks were selected in each location (with the exception of Melbourne which included only 2). In order to assess a worst-case scenario sampling was to be undertaken just after rainfall following a dry period and established rainwater tanks in urban areas with suspected chemical pollution were targeted. The initial project objectives were to monitor rainwater tanks in each of the localities twice per year, during summer and winter following rainfall. As the project period coincided with extended drought conditions Australia wide, this was not always possible. Cities, number of tanks and project partners are shown below in Table 1.

Table 1 Locations of water quality study, number of tanks in the study and project partners for the national reconnaissance.

City	# of tanks	Authority
Adelaide	6	SA Water
Brisbane	6	Brisbane City Council
Canberra	6	ACTEW
Broken Hill	6	NSW Health
Melbourne	2	Yarra Valley Water
Sydney	6	Sydney Water
Wollongong	6	Sydney Water

The characteristics documented for each of the rainwater tanks in the study included potential pollution sources (industry, proximity of major roads, vegetation proximity etc), materials, age and condition of the rainwater tank and roof-catchments including guttering etc, rainwater tank capacity, end-uses and general characteristics relating to treatment devices where used. This data is still being evaluated.

Sample collection and analysis

Water samples in each location were collected by the various project partners and transported to the analytical laboratories according to a standard operating procedure (SOP) developed by the project team. The number of rainwater tanks sampled and the laboratories conducting the analysis were

the same for chemical analysis and microbial analysis. Note that not all analyses were conducted by each laboratory.

Water quality monitoring

Physicochemical

The physicochemical parameters analysed for across the laboratories included temperature at the time of sampling, pH, conductivity, TDS and total suspended solids, turbidity, colour and organic carbon, ionic composition and nitrogen compounds.

Chemical

Chemical analyses included pesticides, fungicides and herbicides, hydrocarbons and volatile organic compounds, phthalates (plasticisers), phenolics, polycyclic aromatic hydrocarbons (PAHs) and trace metals.

Discussions with various research partners during the early stages of the project we are reporting on here highlighted that there were several projects involving urban rainwater tanks either underway or about to start, and these are listed below:

- (i) Water quality study on thirty rainwater tanks in Brisbane by Brisbane City Council. 29 tanks were monitored for a 2 year period.
- (ii) Tank-catch behaviour and roof runoff chemistry (first flush) research being conducted by the Department of Natural Resources and Mines in South East Queensland.
- (iii) Water quality study on two buildings with rainwater tanks in Centre for Education and Research in Environmental Strategies (CERES) in Melbourne, carried out by Yarra Valley Water.

It was therefore decided that the rainwater tank project would incorporate these existing activities and endeavour to add value by supplementing the planned monitoring programs where appropriate and feasible. Data relating to these studies is from the research report from this study (CRC WQT, 2006) in which all participants listed above were partners.

Hot water systems – Brisbane City Council

The use of hot-water systems as a form of disinfection was investigated during a 2yr study by Brisbane City Council. Thirty tanks with mains water top-up were initially recruited into the program, though one participant dropped out of the program before completion due to a change of ownership. Rainwater Tanks (RWT's) were between 3000-5000L capacity and were filled with water from the municipal supply when water levels were low. Of the HWS's connected to the tanks, most were solar (19) with 1 gas and 1 heat pump included. Sixteen houses (53%) had roofs with trees over the roofline, another thirteen houses (43%) had trees within 5m of the roof and one house had no trees near the roof. Samples were taken for physico-chemical analysis each month and heavy metal analysis quarterly (CRC WQT, 2006).

Roof runoff chemistry and catch behaviour - Natural Resources and Mines

Researchers at the Department of Natural Resources and Mines in Brisbane have been researching roof runoff chemistry for three homes in SEQ over a one-year period. In addition they have

reported on 4 years of rainwater tank catch behaviour at the Healthy Coast, Queensland, Australia. A summary of the major outcomes from these studies is included in this paper (Gardner et al, 2004)

RESULTS & DISCUSSION

National reconnaissance

Temperature and pH

The results for the physico-chemical analysis are presented in Table 2. The mean temperature and range varied for each city. As expected the lowest average temperatures were found in Canberra and Adelaide, 12°C and 15.1°C respectively. Brisbane had the warmest average temperature with 25.5°C. Of the tanks tested the mean pH was 6.7 (range 3-7.8) with 30% of samples below the recommended ADWG 2004 range (6.5-8.5). Adelaide had 3 tanks that were acidic during the first sampling event and one different tank that was extremely acidic (pH =3) in the second sampling. The later sample had consumed any buffering capacity in the water as evidenced by the alkalinity value of zero. The Brisbane tanks had a pH of less than 6.5 at both sample times. Broken Hill had one tank with acidic pH during the second sampling. Canberra and Sydney had several tanks with low pH with the same tanks tending to low pH at both sample times, though not consistently. A summary of the distribution of pH values is shown in Figure 1. As shown, >90% of tanks had pH values of <7.5 with the greatest number of tanks between 7 and 7.5.

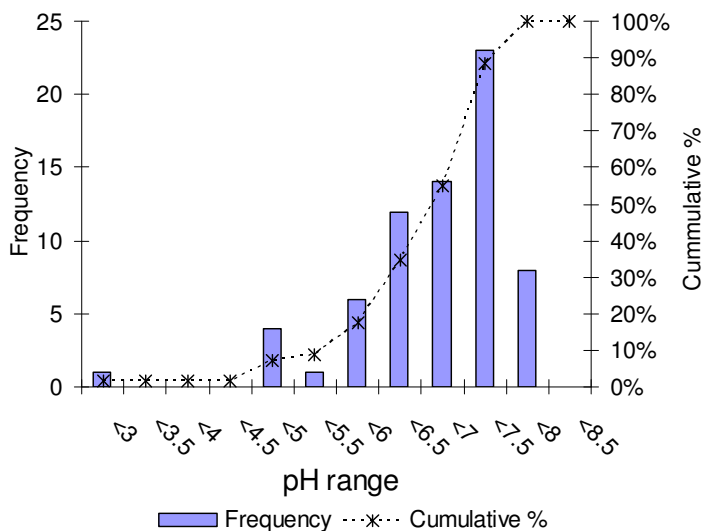


Figure 1. Frequency of pH values for national reconnaissance data.

Conductivity, TDS and Total suspended solids

The conductivity of tanks was generally low ranging from 6-300 $\mu\text{S}/\text{cm}$ with a mean value of 51 $\mu\text{S}/\text{cm}$. For comparison, the conductivity of Brisbane municipal supply is approximately 400 $\mu\text{S}/\text{cm}$. Total Dissolved Solids (TDS) was accordingly low as it was measured by conductivity and the maximum value of 160mg/L was well below the aesthetic value of 500mg/L. The total suspended solids (TSS) was only measured at Broken Hill where 4 samples in the second round

detected TSS with a mean value of 5.7mg/L. The second round of sampling was done during a dry period at Broken Hill and could relate to dust in the tanks.

Turbidity, Colour and Organic Carbon

The turbidity was generally low in all tanks with a maximum value of 3.8 NTU, which is below the ADWG aesthetic value of 5 NTU. True color did exceed the ADWG aesthetic value in one tank in Brisbane for both samples and one tank in Broken Hill for both samples (7% samples). Total organic carbon (TOC) averaged 1.5 mg/L, most of which was dissolved organic carbon (DOC).

Ionic composition and nitrogen compounds

Nitrogen was present in all tanks in low levels in the form of ammonia and nitrate, with the more toxic nitrite detectable at 6µg/L in only one of 12 samples from 6 tanks in Adelaide. All nitrogen compounds were below the ADWG (2004). The presence of nitrate but usually no nitrite indicates an oxidizing environment is present in most tanks. The ammonia present is possibly from degradation of organic matter in the tank. The tank water was soft in all samples with the maximum hardness value below the recommended minimum of 60mg/L as CaCO₃. This corresponds with the low levels of cations and anions seen in tank water samples. Sulphate and Nitrate ions are often linked to industrial emissions and a low pH (Aherne and Farrell, 2002; Ayers *et al.*, 2002) though no relationship was seen in the reconnaissance data.

Pesticides, fungicides and herbicides

A range of pesticides, herbicides, fungicides and pyrethroids were tested. Each laboratory tended to have their own suite of chemicals tested which lead to only partial consistency between laboratories. Of the range of chemicals tested there was only one tank from the second sampling in Brisbane that detected the herbicide CPA (4-chlorophenoxy acetic acid) at a level of 366µg/L in tank water. The same tank did not have any present in the first round of testing. Brisbane was the only location that tested for CPA so this result is out of 11 samples in total that were tested for CPA. All other samples from all locations did not detect any chemicals of this class.

Hydrocarbons and volatile organic compounds

Sydney and Wollongong were the only laboratories which tested for general hydrocarbons. Of these samples there were 2 tanks in Wollongong in the second sampling that detected hydrocarbons in the C15-C28 carbon length range at concentrations of 0.4 and 0.1 mg/L, while all other samples did not detect any hydrocarbons. No BTEX compounds were detected, although not all laboratories tested for all compounds.

Phthalates (plasticisers) and phenolics

Brisbane, Canberra and only the second sampling for Sydney and Wollongong tested for a range of phthalates that totaled 34 samples. Only two tanks (6%) in the second sampling in Canberra detected bis (2-ethylhexyl) phthalate in two tanks at concentrations of 47µg/L and 310µg/L which are both above the 10 µg/L ADWG value for di(2-ethylhexyl) phthalate and di(2-ethylhexyl) adipate. Phthalates are ubiquitous in nature and it is difficult to obtain a clean analytical blank, so this finding may be of little significance. Of the samples tested there were no phenolic compounds detected in any tanks.

Polycyclic Aromatic Hydrocarbons (PAHs)

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

Trace metals

The summary of results for trace metal analysis is presented in Table 2. Not all trace metals have ADWG levels set, however of the metals where a guideline level is given, only lead, zinc and one sample for total aluminium equaled or exceeded the ADWG (2004) for health or aesthetics. Of these the main health concern is lead. Lead was detected in 79% of tanks, with 6 tanks (9%) having levels equal to or exceeding the ADWG (2004). The high lead values originated from one tank each in Brisbane and Canberra, two samples from the same tank in Wollongong and two samples from different tanks in Broken Hill. Zinc levels of greater than 3mg/L were found in 7 samples from Adelaide, of which 5 are from the second sample round, and 2 samples from each round of sampling in Broken Hill, both from the same tanks (total = 4). 3mg/L is the aesthetic ADWG (2004) level for zinc and is associated with taste but not health problems. One sample from Adelaide had total aluminium of 241µg/L that is above the ADWG aesthetic value for soluble aluminium. This guideline level is based on post flocculation problems and not health. Furthermore, soluble aluminium was not detected in this sample and hence aluminium is not of concern from this data. All other trace metal levels were below the ADWG (2004) health and aesthetic values.

Hotwater systems

All Brisbane tank water samples had some copper present with a mean concentration of 0.06 mg/L and a maximum of 1.23 mg/L. The maximum concentrations did exceed the aesthetic but not the health 2004 ADWG value. There was a significant ($P < 0.01$) though weak correlation ($R^2 = 0.22$) of copper concentration and pH in hot water taps connected to the rainwater tank. Unfortunately there is not sufficient data from hot water systems connected to mains water supplies for statistically valid comparisons, though the average copper concentration for hot water systems connected to mains water supply is lower than those connected to rainwater tanks (0.087mg/L, N=7 compared to 0.281mg/L, N=126).

Lead was detected in 19% of rain-water tank samples from Brisbane and the concentration was found to be equal to or above the ADWG (2004) of 0.01mg/L in 7% (14 / 205) of samples tested. By comparison the municipal water had only one sample (0.5% with a lead concentration \geq 2004 ADWG and the incidence of lead detection was only 1%. The high lead concentrations in rainwater samples came from 10 separate locations with only 3 tanks having more than one sample with elevated lead levels. Eighteen of the 30 tanks tested did not detect any lead at all.

First flush devices

Outcomes of studies on first flush water quality are presented in Gardner et al (2004). The overall behaviour of metal chemistry through runoff events was found to be highly variable and complex. There were large differences between rainfall events. In terms of trace metals there was a first flush effect for particulate lead but generally not for particulate zinc. There is also a reduced catch-efficiency due to the use of first flush devices (Gardner et al, 2004).

Table 2 Results of testing for trace metals from National Reconnaissance

	Total detected	Total tested	Mean	Standard deviation	Min	Max	ADWG Health	ADWG aesthetic
Total Aluminium	54	69	41.6	36.2	10	241		
Arsenic	3	27	1.0	0.0	1	1	7	
Antimony	0	16	na	na	0	0	3	
Barium	14	21	6.4	3.9	2.4	18	700	
Beryllium	0	10	na	na	0	0		
Cadmium	8	69	0.9	0.3	0.6	1.4	2	
Total Chromium	4	69	9.8	9.7	2	23	50¹	
Cobalt	1	58	0.7	na	0.7	0.7		
Total Copper	60	69	18.4	38.6	1	220	2000	1000
Total Iron	44	69	44.8	46.7	10	181		300
Total Lead	53	69	3.8	3.3	0.3	13²	10	
Total Lithium	2	44	3.5	0.7	3	4		
Manganese	67	69	10.2	10.7	0.5	53	500	100
Molybdenum	0	16	na	na	0	0	50	
Total Mercury	1	45	0.4	na	0.4	0.4	1	
Total Nickel	18	69	2.0	1.3	0.5	5	20	
Selenium	0	16	na	na	0	0	10	
Silver	0	16	na	na	0	0	100	
Strontium	46	48	15.2	19.7	2	90		
Total Tin	0	24	na	na	0	0		
Total Zinc	69	69	1790	3099	12	13400³		3000

¹ Chromium as CrVI.

² Data for lead (maximum) exceeds the health value.

³ Data for zinc (maximum) exceeds the aesthetic ADWG 2004 values.

CONCLUSIONS

Overall the chemical water quality shows that rainwater in Australia is soft water with low total dissolved solids or salts which is in agreement with studies in other countries (Hontoria *et al.*, 2003). Water from tanks in urban Australia is generally slightly acidic but cannot be regarded as acid rain with the exception of one sample from Adelaide with a pH of 3. Acid rain is where the pH is lower than the acidity of pure water in equilibrium with CO₂ in the atmosphere, which is a pH of <5.6 (Avila and Alarcon, 1999; Hu *et al.*, 2003). The lack of acid tank water is an indication that industrial and motor vehicle emissions are not significant inputs to rainwater in the locations where these samples were taken. However, storage in tanks may neutralise some acidity through reaction with dust and organic matter also collected in the tank. The variability of tank water pH is much greater than municipal supply as shown by the Brisbane City Council 30 tank study (CRC WQT 2006). This high variation in water quality between tanks and over time makes it more difficult for

assessment of the risk with different end uses of tank water. The soft and sometimes acidic nature of the rainwater is likely to cause corrosion of pipes and this is suggested from the results of the Brisbane and Melbourne data, where tank water passing through the hot water system had higher levels of copper and greater incidence of detection for lead and nickel (CRC WQT, 2006). The generally soft water may also be a risk for electrical hot water systems that have a sacrificial anode designed for hard water such as in Brisbane municipal supply. This could lead to an overactive anode and production of explosive hydrogen gas.

Given that lead is present in levels that may affect health in 5-10% of tanks (i.e. is above 2004 ADWG levels) it is presently not recommended for drinking. This is particularly so for children and infants who are more susceptible to permanent developmental effects from consumption of low levels of lead (Hivert *et al.*, 2002). If tank water is to be used for drinking then an ion exchange filtration system would be recommended to remove heavy metals. The level of copper, lead, nickel and other metals in hot water supplied by rainwater tanks may preclude the use of rainwater in hot water systems if all risk of exposure to heavy metals is to be avoided. When examining other chemical contaminants on an individual basis in the majority of situations the chemical water quality from rainwater tanks is unlikely to cause any chemical related health problems if it is drunk. However, this is not always so in some tanks or at certain times. Further research will examine the chemical water quality of water from urban rainwater tanks considering air pollution sources and bulk deposition to roof surfaces and inputs from the rainwater catchment itself.

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