Determining the sediment dynamics in a rainwater tank

Détermination de la dynamique des sédiments dans un réservoir d'eaux pluviales

M.I. Magyar*, V.G. Mitchell*, A. Ladson*, C. Diaper**

*Institute for Sustainable Water Resources, Monash University, Department of Civil Engineering, Building 60, Wellington Road, Clayton, VIC 3800, Australia Mirela.Magyar@eng.monash.edu.au ; Grace.Mitchell@eng.monash.edu.au ; Tony.Ladson@eng.monash.edu.au.

**CSIRO Land and Water, Water for a Healthy Country Flagship, P.O. Box 56, Graham Road, Highett, VIC 3190, Australia, Clare.Diaper@csiro.au.

RESUME

Les réservoirs d'eaux pluviales sont de plus en plus utilisés dans les milieux urbains en Australie en tant que source alternative d'eau potable. Une étude d'un réservoir à échelle réduite et d'un réservoir taille réelle montre que les concentrations en métaux lourds peuvent excéder les limites qui sont données dans les directives nationales. De très hautes concentrations en métaux lourds ont été trouvées dans les sédiments au fond des réservoirs. Nous sommes en train d'étudier le procédé de mouvement des sédiments dans un réservoir à taille réelle. Les résultats préliminaires montrent l'effet de la mise en suspension sur la qualité de l'eau déversée à l'exutoire du réservoir. Le but de notre futur travail est d'améliorer le design des réservoirs afin de réduire la mise en suspension des sédiments.

ABSTRACT

Rainwater tanks are being introduced into urban areas in Australia to supplement centralised potable supply systems. A pilot scale tank study and a full-scale field tank study found that heavy metal concentrations in water samples taken from the tank's supply point can, in some cases, exceed water quality levels recommended by guidelines. Both studies also found very high concentrations of heavy metals in the sediments accumulated at the base of rainwater tanks. Laboratory experiments are underway to investigate sediment transport processes within a full-scale tank. Preliminary results demonstrate the effect of sediment re-suspension on the quality of water released from the tank outlet. Improved tank designs that reduce sediment re-suspension and mitigate impacts on water quality are the focus of future work.

KEYWORDS

Heavy metals, Rainwater tanks, Sediments

1 BACKGROUND

In Australia, population growth, prolonged drought and growing concern about the potential consequences of climate change have highlighted the need to alter the way we value, supply, and use water. Increased scarcity means we need to examine future options for the delivery of water services. Amongst the range of alternative water source options being implemented in Australian cities, rainwater tanks offer the potential to supplement centralised potable supply at house scale.

Since July 2005, in the State of Victoria (Australia), newly built houses must meet a '5 Star' standard which includes the option of using rainwater tanks (Building Commission Victoria, 2005) and in other States their use is becoming common practice. Rainwater tanks are also supported by Victorian government incentives for water smart products (DSE, 2006). Large scale integration of rainwater tanks into the urban environment represents the transfer of ownership, operation and maintenance of part of the water supply system to property owners and occupants rather than water authorities.

Although rainwater tanks have long being used in Australia, particularly in rural areas, their increased use in urban areas and their inclusion in government policies has created renewed interest in the quality of water that they deliver. To limit the problems that may occur when using rainwater tanks, it is important that rainwater tanks are well designed ensuring fit-for- purpose water quality is reliably supplied. Maintenance requirements must also be achievable, ensuring the long term success of rainwater tanks integration into urban water systems. Recently, questions have been raised about the microbiological and chemical water quality of water sourced from tanks and the potential adverse effects if rainwater is used for drinking, clothes washing, bathing or irrigating edible foodstuffs.

Studies in Australia (Coombes et al., 2000; Thomas and Greene, 1993) and overseas (Gromaire et al., 2001; Simmons et al., 2001) have found heavy metals from the roof runoff being delivered into the rainwater tanks and accumulating in the sludge (Coombes et al., 2000; Gardner et al., 2004).

This current study has identified that poor rainwater tank design may increase the risk of the sediment and bound heavy metals (accumulated at the base of the tank) being mobilised during rain events and transported to the end use. This is because it is common for rainwater tanks to position the outlet pipe at the base of the tank, creating the potential for releasing the most polluted water from the tank.

There are three components of this study:

1) assessment of water and sediment quality in six pilot tanks connected to trial roofs made of different materials situated at the same location;

2) assessment of water and sediment quality in nine tanks at residential houses;

3) laboratory experiments that investigate the impact of sediment mixing and re-suspension on water quality delivered from the tank.

2 METHODS

2.1 Pilot roofs and tanks

Six pilot tanks were monitored over a one year period, on a quarterly basis. The tanks were 0.1kL in size, connected to a $3.7m^2$ roof. Three roof materials (glazed tiles, Zincalume® and Colourbond®) were constructed with and without lead flashing (of $0.26\ m^2$ area), resulting in six different roofing combinations.

Sampling was conducted during dry days, 2 to 6 days after a rain event. Water samples were collected from the tap which is positioned close to the base of the tank. Sediment samples were collected by emptying the water from the tanks. The samples were analysed for pH and concentrations of Al, Cd, Cu, Cr, Fe, Mn, Ni, Pb, Zn. The water quality analyses were performed according to standard methods 3030D and 3120B respectively (APHA, 1995), by NATA accredited laboratories. More details are presented elsewhere (Magyar et al., 2006a).

2.2 Urban roofs and tanks

Nine full scale residential suburban tanks were investigated. Eight of these tanks (F2 to F9) were located approximately 5km north-west of central Melbourne, all within 500m of each other. Tank F1 was situated in a south eastern suburb some 40km from the other eight tanks. The characteristics of the tanks and roofs are presented in Table 1. All tanks were retrofitted to existing houses, such that they were between 4 months (tank F8) to 20 years old (tank F5).

Field Tank	Tank material	Size, kL	Roof material	Outlet height from base, mm	Proximity to road, m	Tank age, years	Maintenance
F1	PVC	4.5	PT,CB, ZnAl	100	15	3	Once a year
F2	PVC	2.25	PVC	90	50	> 3	Very rarely
F3	PVC	2.75	GI	50	50	> 3	Very rarely
F4	ZnAl	2	GI	40	50	> 3	Very rarely
F5	Con	23	Tiles	150	50	20	Very rarely
F6	PVC	2.25	Tiles	60	50	> 5	Very rarely
F7	PVC	2.27	Tiles	40	15	3.4	Once/2 year
F8	ZnAl	2	ZnAl	35	15	4month	New tank
F9	St.St.	0.23	PM	30	15	7	One/1.5 year

PT- painted tiles; CB- colourbond; ZnAl- Zincalume; GI-Galvanised iron; St.St.- Stainless Steel; PM-Painted metal; PTS-Power Terminal Station; Con- Concrete

Table 1 : Characteristics of urban roofs and tanks

Sampling was conducted 2 to 7 days after a rain event. Water samples were collected from the outlet tap positioned close to the base of the tank (Table 1). All tanks were full of water at the time of sampling.

The sediment accumulated at the base of the tank was sampled with a specially designed sampler (Figure 1). After grabbing the sediment, the sampler rotates to a vertical position closing itself with the fixed positioned lid, thus avoiding loss of unconsolidated matter from the ladle.

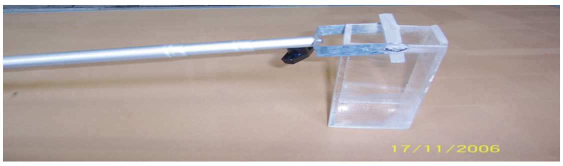

Figure 1 : Sediment sampler

Water and sediment samples were analysed for pH and concentrations of Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn by NATA accredited laboratories. Water and sediment samples were fractionated in three wet fractions: >63 μ, between 0.45-63 μ and <0.45 μ and analysis of metals was performed in each fraction. Fractions of water samples were separately digested by Suprapur nitric acid method (standard method 3030E) (APHA, 1995) and analysed with an ICP OES.

Fractionated sediment samples were also analysed for metals on a dry weight basis. Fractions were oven dried (at 105°C) over night and a pre-weighted sub-sample was acid digested with Suprapur nitric acid. The method is a verified laboratory in-house developed method with a recovery between 80-120%. For each batch of samples, blank tests, duplicates, standard reference materials (for trace metals) and spikes were analysed to verify results (APHA, 1995).

Sediment samples were also analysed for TSS and density (not reported here) and particle size distribution (PSD). The PSD tests were performed by light scattering method using a Malvern Mastersizer version 5.22 and the results are reported elsewhere (Magyar et al., 2006b).

As there are no specific guidelines for water quality from rainwater tanks, the Australian Drinking Water Guidelines (ADWG) (NHMRC & NRMMC, 2004) were used as reference. Additional guidelines used for comparison were Recreational Water Guidelines (RWG) which include primary contact such as swimming and bathing (ANZECC and ARMCANZ, 2000b) and Agricultural Irrigation Guidelines (AIG) (ANZECC and ARMCANZ, 2000a). For sediments, the EPA guidelines for disposal of waste (EPA Victoria, 2004) were used for reference for metals.

2.3 Laboratory experiments

Preliminary laboratory experiments have been conducted to simulate an urban tank filling during a rain event, using a 2.25kL clear PVC cylindrical tank. Variation in TSS concentrations was used to asses sediment transport, with TSS analysis using method 2540D (APHA, 1995). The tank has outlets positioned at different heights relative to tank's base, starting at 50mm up to 300mm. The three experiments conducted thus far were run with a constant 1L/s inflow rate. The inflow water pipe was positioned close to the tank's wall and opposite the outlets for the first experiment and in the middle of the tank for the following two experiments (Figure 2). Sand particles >150 μ and thicknesses of 1 cm and 2 cm were used to represent the sediment layer on the base of the tank. Water samples were taken from each outlet when the water level reached that level and every time the water level reached a higher level. Further details of the laboratory experiment design are presented in Magyar et al. (2006b).

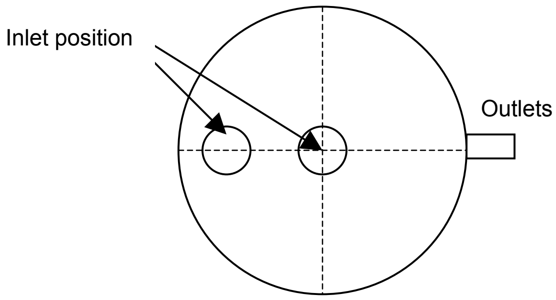

Figure 2 : Top view of laboratory tank set-up

3 RESULTS

3.1 Pilot tanks

The following provides a summary of the results. More detailed results can be found in Magyar et al. (2006a). The tile roof with no Pb flashing had at least one water sample with Cr, Fe, Mn, Ni and Pb concentrations exceeding the ADWG values. The tank water from the Colourbond® and Zincalume® roofs without flashing did not exceed ADWG recommended limits for the whole period of investigation.

All three tanks connected to roofs with Pb flashing presented Pb in concentrations up to 50 times greater than the guideline level. The Colourbond® roof with Pb flashing gave the highest concentration of Pb in tank water (0.5 mg/L), whereas the glazed tile roof with Pb flashing produced the lowest concentration (0.29 mg/L). It was concluded that any Pb flashing on the roof will significantly contribute to Pb content in tank water.

In the sediments (sludge), the high concentrations of Cu, Pb and Zn classified the sludge as a 'prescribed soil' (waste) (EPA Victoria, 2004) requiring appropriate management options for disposal to licensed sites using licensed transport permits. The roofs with Pb flashing presented sediments with Pb concentrations exceeding the 'prescribed soil' maximum level of 3,000mg/Kg, with 24,220 mg/kg observed for the Colourbond® roof.

3.2 Urban roofs and tanks

The measured heavy metals from the water samples are presented in Figure 3. The concentrations of Al, Cd, Fe and Zn exceeded the ADWG (2004) acceptable levels in at least one tank (Figure 3a, 3b, 3c, 3d) with tank F7 presenting the highest values for Al and Fe. All the other tanks met the RWG (2000) and AIG (2000) recommended values for Al and Fe. The water from tank F7 showed Pb levels 35 times more than the ADWG (2004) acceptable level and 7 times more than the RWG acceptable levels making the tank water unacceptable for recreational purposes (Figure 3e). The concentrations of Pb in the tank water exceeded the ADWG values in 5 of the 9 tanks under investigation (Figure 3f- log scale graph). High levels of Pb were observed (still within guidelines) in tank F8, although the tank had been in use for only 4 months at the time of sampling.

The fractionation of water samples (>63 µ, 0.45-63 µ and <0.45 µ) found that the fraction >63 µ may contain a considerable amount of some metals as shown in Figure 4 (only Fe and Pb are shown). Metals such as Cd, Cu, Mn, Ni and Zn were found mostly in a dissolved form, where Al, Cr, Fe and Pb were in a particulate form. This finding is important for future laboratory tests, where sediment re-suspension will be monitored for a range of particle sizes. Acidic pH was observed in all the tanks, ranging from 4.3 to 4.9 explaining the prevalence of the dissolved form for some metals. The measured density of the sediments was found to be equivalent to sand.

Results of sediments are presented in Figure 5. All metals except for Cr exceeded the maximum concentration allowed in soils to be disposed of as fill material, classifying the tank sediments as ' prescribed soil' (EPA Victoria, 2004). In some of the tanks, the high concentration of Cu (tanks F2, F9), Pb (tank F5) and Zn (tanks F2, F3, F4, F5 and F8) exceeded the maximum values for 'prescribed contaminated soil'. This implies that sediments from these tanks need to be immobilised prior to disposal.

This finding implies that a specialised service needs to be employed for tank maintenance. Also, those tanks may need to be serviced on a more regular basis to avoid the build-up of such high levels of heavy metals in sediments and the requirement for a special treatment prior to disposal.

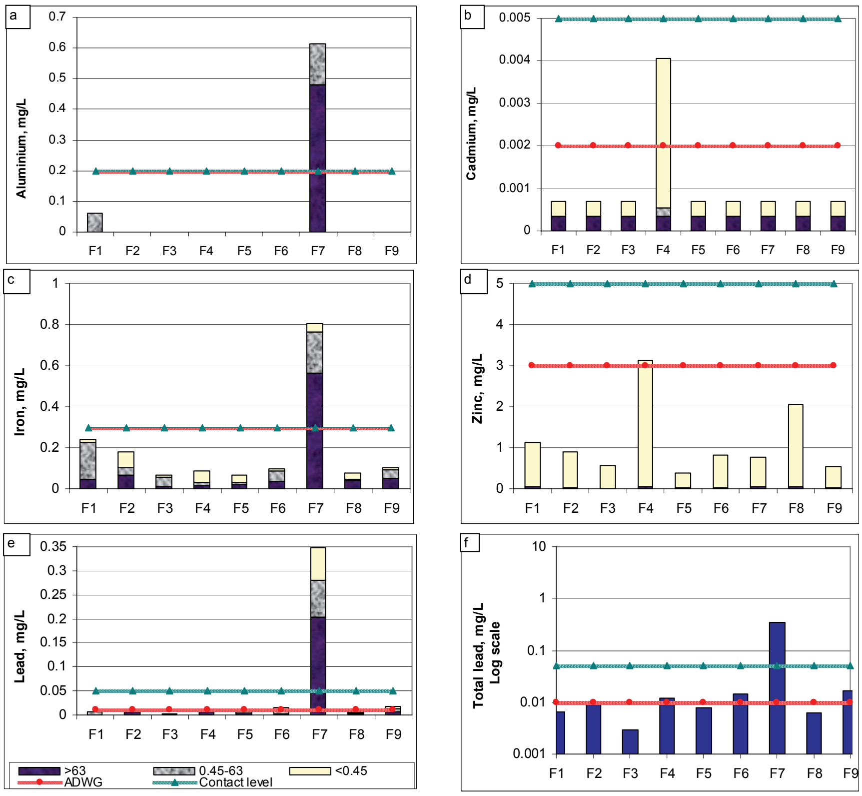

Figure 3 : Metal concentrations in water samples

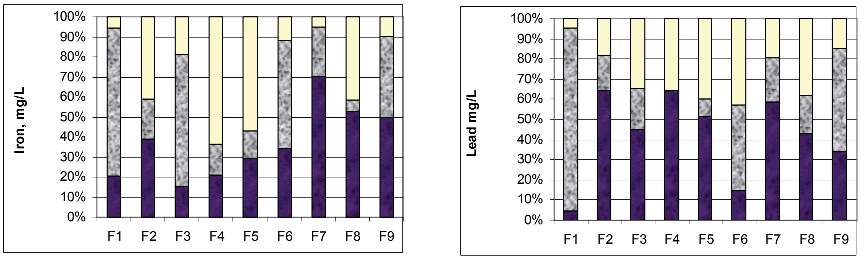

Figure 4 : Fractionation of Fe and Pb

3.3 Laboratory experiments

Preliminary results show that the position of inlet can have great impact on outlet water quality, re-suspension of already settled sediments being greater for a close to the wall, opposite inlet than a centrally located inlet (Figure 6). At the same time, increase in the thickness (volume) of sediment can significantly affect outlet water quality as shown in Figure 6, while a buffer layer of water above the sediment will greatly reduce re-suspension. However, if water is to be used for a number of end uses in the real urban set-up, a buffer layer may not be available at all times. Additional experiments will be run for other particle sizes and flow rates.

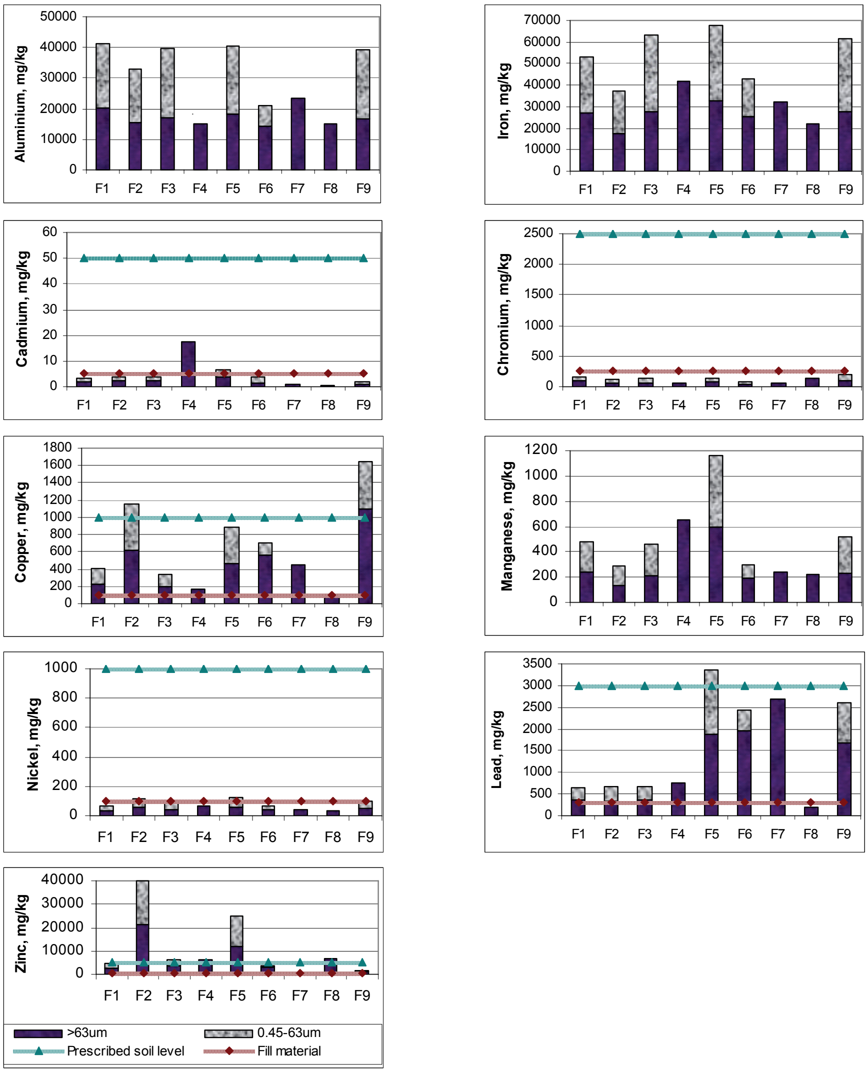

Figure 5 : Concentration of metals in sediments

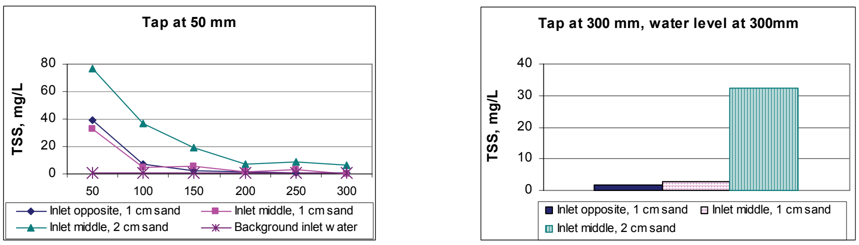

Figure 6 : Sediment re-suspension as a TSS measurement

4 CONCLUSION

Water and sediment in urban rainwater tanks exhibited higher heavy metal concentrations than comparable samples from small scale pilot tanks despite all the urban tanks being full of water at the time of sampling. This outcome can be attributed to the infrequent maintenance of the tanks. Lead levels exceeding ADWG in the urban tanks highlighted the need to investigate the mechanisms determining heavy metals levels in the outlet water. One urban tank in particular presented concentrations at levels of concern, 35 times over the ADWG limits and 7 times over the RWG levels, making the water unsuitable for drinking and recreational purposes. All other tanks met both guideline levels.

The sediments in the urban tanks were found to contain metal concentrations that are a potential source of pollution and require appropriate management options for disposal to licensed sites using licensed transport permits. Preliminary laboratory experiments on sediment re-suspension within the tank show that careful design of tanks is important to ensure the water quality delivered to the end use is fit-for purpose. Tanks design solutions that reduce sediment re-suspension and promote easy removal of sediment will be further explored to mitigate impacts on water quality delivered to the end use.

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