Microbiological risks of recycling urban stormwater via aquifers
D. Page, D. Gonzalez and P. Dillon

ABSTRACT

With the release of the Australian Guidelines for Water Recycling: Managed Aquifer Recharge (MAR), aquifers are now being included as a treatment barrier when assessing risk of recycled water systems. A MAR research site recharging urban stormwater in a confined aquifer was used in conjunction with a Quantitative Microbial Risk Assessment to assess the microbial pathogen risk in the recovered water for different end uses. The assessment involved undertaking a detailed assessment of the treatment steps and exposure controls, including the aquifer, to achieve the microbial health-based targets.

Key words | managed aquifer recharge, microbial health-based targets, quantitative microbial risk assessment, urban stormwater

INTRODUCTION

Urban stormwater harvesting is increasingly regarded as an appropriate and cost effective option in Australia for augmentation of urban water supplies (NRMMC–EPHC–AHMC 2009a). Common drivers for stormwater recharge have included severe water shortages in dry periods, climate change, stricter regulations on discharges to receiving environments and growing urban populations. These drivers have resulted in an increasing interest in a range of stormwater harvesting schemes, including managed aquifer recharge (MAR), as a method for storing and treating urban stormwater. The Australian Guidelines for Water Recycling: Managing Health and Environment Risks (NRMMC–EPHC 2006) and its supporting Phase 2 Guidelines including the Australian Guidelines for Water Recycling: Managed Aquifer Recharge (‘MAR Guidelines’) (NRMMC–EPHC–AHMC 2009b) provide a framework to assess the risk to human health and the environment. This provides opportunities to make more effective use of the growing scientific knowledge on pathogen removal characteristics of aquifers (Schijven & Hassanizadeh 2002; John & Rose 2005; Pang 2009).

In 2005, a purpose built MAR site utilising aquifer storage transfer and recovery (ASTR) was established to evaluate the urban stormwater use options in Adelaide, South Australia, including for drinking (Page et al. 2010). Special attention has been given in this paper to the options in which MAR is integrated within the proposed broader water treatment train. This paper adopts the approach given in the Australian Guidelines for Water Recycling Phase 2C MAR to determine the microbial health-based targets (log_{10} removals) for various options, based on pathogen decay rates and subsurface residence time, to assess if the required microbial health-based targets are achieved. The MAR guidelines currently do not account for filtration or sorption attachment as removal processes. Further scientific information is required to validate methods to measure relevant parameters and verify predictions of removals of these processes at field scale in heterogeneous aquifers at MAR sites. The specific objective of this paper is to evaluate the human health risks of options for harvesting, treating and subsequently supplying urban stormwater via an aquifer, as shown in Figure 1.

Figure 1 shows the conceptual options for harvesting of urban stormwater and aquifer storage with different end uses and treatment options. End uses were categorised according to exposure, with public space irrigation having the lowest level and drinking water the highest.

Pre-treatment options could include either natural (e.g. wetlands) or engineered systems (e.g. UV disinfection). Intermediate treatment of recovered aquifer water prior to pumping to a drinking water reservoir would involve engineered processes to ensure the quality of the treated...
stormwater either matches or surpasses the quality of the resident reservoir water.

The post-recovery treatment processes would depend on the water quality required for the respective end use. Water used for open space irrigation would not need to be treated to the same extent as non-potable internal household use, and this in turn would not require the same level of treatment to meet drinking water standards.

**METHODS**

Each of the potential stormwater harvesting options that involve aquifer treatment from Figure 1 is evaluated systematically to determine the potential end uses. The process also identifies potential treatment and exposure barriers to protect human health.

Microbial performance targets are expressed in terms of required $\log_{10}$ reductions. The two parameters required for calculation of performance targets are pathogen concentrations in urban stormwater and exposures associated with identified uses of urban stormwater.

Urban stormwater pathogen concentrations can vary over a wide range and 95th percentiles should be used in determining the achievement of health-based targets. Given the lack of data on pathogens in stormwater internationally, the default assumption, that Australian urban stormwater contains 1.8 *Cryptosporidium*, one rotavirus and 15 *Campylobacter* per litre (95th percentile) was used (from the Stormwater Harvesting and Reuse guidelines, **NRMMC–EPHC–AHMC 2009a**).

Indicative exposures associated with particular uses of urban stormwater are provided in the Australian Guidelines for Water Recycling Phase 1 (**NRMMC–EPHC 2006**). These include 1 mL exposure 50 times per year for open space irrigation and 2,000 mL daily for drinking water.

These default values were used to determine the performance targets and necessary $\log_{10}$ reduction calculations were performed as described below:

$$\log_{10} \text{reduction} = \log \left( \frac{\text{number of organisms in stormwater} \times \text{exposure (L)} \times \text{frequency}}{\text{dose equivalent to } 10^{-6} \text{ DALY}} \right)$$

where the dose equivalent to $10^{-6}$ DALY, taken from **NRMMC–EPHC (2006)**, for:

- Rotavirus $= 2.5 \times 10^{-3} \text{ n/L}$
- *Cryptosporidium* $= 1.6 \times 10^{-2} \text{ n/L}$
- *Campylobacter* $= 3.8 \times 10^{-2} \text{ n/L}$
The credit of log_{10} removals for the aquifer and wetland was calculated as the product of the average residence time (in days) in the wetland or aquifer and the average pathogen decay rate (in log_{10}/day). Mean residence time in the aquifer (~250 days) was calculated from the break through of a conservative tracer (conductivity) during the flushing of the brackish aquifer with fresh stormwater. Details of the approach and additional modelling are given in Kremer et al. (2010). The pathogen decay rates were measured in situ in the wetland and aquifer using the pathogen decay chamber method as outlined in previous studies (Sidhu et al. 2010).

RESULTS AND DISCUSSION

In the development of the MAR and stormwater use options research project, an integrated approach to managing risks was adopted which includes assessment of the aquifer treatment barrier and risks in the end use. In valuing the aquifer treatment capacity, integrity and independence of preventative measures, MAR can be treated in the same way as conventional engineered water treatments such as UV disinfection or chlorination.

Initially, the potential options in Figure 1 may be expanded into at least twelve potential MARs and stormwater use options for Adelaide based on the Parafield stormwater harvesting system. Each of the options is arranged by end use ranging from the lowest exposure (open space restricted irrigation) to the highest (drinking water). This methodology makes explicit the barriers and preventative measures that are in place for each of the potential options.

The potential options are then analysed to determine how the treatment barriers can be used alone or in combination with on-site preventive measures such as restricted irrigation to calculate the required microbial health-based log_{10} reduction targets. Two options, open space irrigation and drinking, which would rely upon the ASTR system, are shown for illustrative purposes. The required log_{10} reductions vary between the different pathogen groups and end uses depending on the exposure (Table 1).

The aquifer treatment component did not account for any straining or attachment for longer than the ‘infective life’ of pathogens onto the aquifer matrix. Only natural biodegradation and predation by native groundwater organisms was considered, which resulted in log_{10} reductions of 1.4, 2.8 and >6.0 for viruses, protozoa and bacteria, respectively. This rank order is consistent with previous assessments of aquifer treatment for secondary treated wastewater (Toze et al. 2010), which showed low attenuation of viruses and protozoa compared with bacteria. The pathogen attenuation rates here were determined from a single experiment with diffusion chambers (Sidhu et al. 2010) and were significantly slower for viruses and protozoa than previous analyses in groundwater influenced by reclaimed water (Toze et al. 2010). Further experimentation is warranted but this conservative removal rate has been adopted for this risk assessment.

The following assessment of risks for the evaluated MAR and stormwater use options can be determined:

- Risks from viruses have the highest microbial health-based targets and if they are met it is likely that protozoan and bacterial targets will also be met, although this should be verified.
- Open space irrigation requires <2.0 log_{10} reduction and can potentially be managed using chlorination, exposure controls and/or MAR.
- Drinking water use requires the highest microbial health-based targets be met which would involve significant treatment. This includes UV disinfection, chlorination and recovery of the water to a nearby drinking water reservoir.

Table 1 groups the most common end use activities in terms of required log_{10} reductions and indicates that for stormwater reuse applications, such as open space irrigation, a 1.5 log_{10} reduction is required. This could be

<table>
<thead>
<tr>
<th>Highest exposure end use</th>
<th>Total inactivation credits (aquifer plus treatments and exposure reduction)</th>
<th>Target inactivation credits</th>
<th>Treatment and exposure reduction controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td>Open space irrigation</td>
<td>3.4</td>
<td>4.8</td>
<td>&gt;6.0</td>
</tr>
<tr>
<td>Drinking</td>
<td>&gt;6.0</td>
<td>&gt;6.0</td>
<td>&gt;6.0</td>
</tr>
</tbody>
</table>
achieved by a mixture of wetland and ASTR aquifer treatment, and by applying simple exposure control such as restricting public access during irrigation.

For drinking water the microbial health-based target is $5.5 \log_{10}$ for viruses (Table 1). However, $5.4 \log_{10}$ can be achieved by wetland, ASTR aquifer treatment combined with UV and chlorine disinfection (Sidhu et al. 2010). If virus removal in wetlands can be validated, or if other engineered treatment options were installed, the total $\log_{10}$ reductions would exceed the target $5.5 \log_{10}$.

**CONCLUSIONS**

The approach used for the human health risk assessment and management of urban stormwater reuse is based on Australian Guidelines (NRMMC–EPHC 2006; NRMMC–EPHC–AHMC 2008). If exposure control is included, then the harvested stormwater would be generally suitable for open space irrigation (with or without MAR). With the addition of UV and chlorination disinfection, the harvested stormwater would meet the microbial health based target requirements of the Australian Guidelines for Water Recycling (Phase 1) and Augmentation of Drinking Water Supplies (Phase 2). However, in addition to meeting these quality requirements, a water quality risk management plan would need to be completed and accepted by stakeholders, regulators and the community.

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