Quantitative microbial risk assessment (QMRA) for water re-use via aquifers

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Worldwide, there is an increasing interest in the recharge of aquifers as a method for augmenting urban water supplies. Managed aquifer recharge (MAR) can utilise a variety of non-traditional source waters including urban stormwater and reclaimed water from sewage effluent. However, these alternate water sources may contain a wide range of pathogenic hazards that pose risks to human health. Hence the safe use of recycling water via aquifers requires potential risks to be reduced to acceptable levels. This article outlines the approach recommended by the draft *Australian Guidelines for Water Recycling (AGWR) (Phase 2C Managed Aquifer Recharge)* [1] to quantify the aquifer treatment using a quantitative microbial risk assessment (QMRA) approach [2].

The first step in a QMRA is to define an acceptable level of risk; this is then used to set health-based targets for individual hazards. Assessing the disability-adjusted life years (DALYs), which accounts for the severity of each hazard, is the recommended approach advocated in AGWR [2], with an annualised risk of 10^{-6} DALYs per person not to be exceeded.

DALYs are applied once pathogen numbers, dose-responses and exposures are determined; that is, after completion of a QMRA. This typically incorporates the following four steps:

- *Hazard identification.* AGWR [2] recommend using the reference pathogen hazards (Campylobacter, *Cryptosporidium parvum,* rotaviruses) to represent bacteria, protozoa and viruses respectively in the QMRA. These hazards are used both for stormwater and reclaimed sewage effluent. This step also includes consideration of the potential variability in pathogen numbers (typically assessment of the mean, median and 95th percentile numbers) as well as the treatment provided by the components of the MAR system.
- *Dose-response.* Establishes the relationship between the dose of the reference pathogen and the likelihood of illness.
- *Exposure assessment.* Identifies the population exposed to the hazard, and the pathway, quantity and duration of exposure. This step includes assessment of both the intended volume of the recycled water (e.g. ingestion of sprays from garden irrigation estimated at 0.1ml) and the frequency of the exposure (default 90 times / year for garden irrigation) [2].
- *Risk characterisation.* Calculates the DALYs to determine if the MAR scheme is of an acceptable risk.

The last step in risk assessment is to integrate information from hazard identification, hazard concentration considering any treatment barriers (including the aquifer), dose-response and exposure assessment, to determine the magnitude of risk. The magnitude of risk should be assessed on two levels – maximum risk (risk in the absence of any preventive measures such as treatment) and residual risk (risk that remains after consideration of existing preventive measures).

Determination of residual risk can be an iterative process, and will depend upon the residence time of the pathogen in the aquifer and its decay rate among other preventive measures. The draft *AGWR phase 2C Managed Aquifer Recharge* [1] advocate that the aquifer can be recognised as a treatment step much like conventional water treatment barriers, such as disinfection, for the deactivation of pathogens.

In cases where a simple exponential decay function can approximate the viable pathogens remaining, the numbers of pathogens in water recovered from a MAR scheme may be

described by $C_t = C_0\ 10^{-t/\tau}$ where C_0 is the initial number of pathogens in the recharge (n/L), t is the residence time (days) and τ is the time required for one-log10 removal. The required log reduction will depend upon the quality of the source water, the total log reduction of all treatment steps (not just the aquifer), the exposure scenario and any other water use controls in place (e.g. with holding periods for irrigation).

For example, the aquifer storage transfer recovery (ASTR) scheme in Salisbury, SA uses urban stormwater which is pre-treated in a wetland and then injected into a confined limestone aquifer prior to recovery from wells located 50m away. Wetland and aquifer residence time calculated by hydraulic modelling were an average of 10 and 270 days respectively. The combined treatment potential of the wetland and aquifer was estimated to be >6 log for removal of the reference pathogens, determined by insitu decay studies (to validate inactivation rates and residence times). The majority of this treatment (>4 log) was within the aquifer due to the longer residence time and warmer temperature than the wetland (~2 log for bacteria). The treatment potential of the ASTR scheme was determined to be satisfactory for use of the recovered water for drinking (residual risk $<10^{-6}$ DALYs). Recovered water and observation wells within the attenuation zone are being sampled as part of the verification monitoring program. Samples are analysed for microbial indicators and reference pathogens to assess the effectiveness of all barriers including aquifer treatment.

Multiple barriers (preventive measures), including source protection, exclusion of water from polluted sources, pre-treatment prior to recharge, aquifer treatment, post-treatment if necessary, and water use controls, together with following a risk management plan on how to manage and monitor these measures, will ensure that the residual risk is acceptable. By understanding each of the barriers an estimate of the required retention time in the aquifer can be made. These processes are described in the draft AGWR Phase 2C [1].

References

1. EPHC, NHMRC and NRMMC (2008) *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks, Phase 2C Managed Aquifer Recharge.* National Water Quality Management Strategy 21. Environment Protection and Heritage Council, National Health and Medical Research Council and Natural Resource Management Ministerial Council. Canberra, Australia. (Public consultation draft) http://www.ephc.gov.au/pdf/water/200805_WQ_GL_Draft_AGWR_MAR.pdf
2. NRMMC (Natural Resource Management Ministerial Council), EPHC (Environment Protection and Heritage Council) & AHMC (Australian Health Ministers' Conference) (2006). *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks. Phase 1. National Water Quality Management Strategy.* NRMMC/EPHC/AHMC, Canberra, Australia.

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