Indigenous microbial surrogates in wastewater used to understand public health risk expressed in the Disability-Adjusted Life Year (DALY) metric

Author:
Owens, CEL; Cox, PT; Byleveld, PM; Osborne, NJ; Rahman, MB

Publication details:
Microbiology Australia
v. 42
Chapter No. 3
pp. 125 - 129
1324-4272 (ISSN); 2201-9189 (ISSN)

Publication Date:
2021-09-01

Publisher DOI:
https://doi.org/10.1071/MA21037

Indigenous microbial surrogates in wastewater used to understand public health risk expressed in the Disability-Adjusted Life Year (DALY) metric

Christopher EL Owens[A,B,C,H], Peter T Cox[B], Paul M Byleveld[D], Nicholas J Osborne[E,F,G] and Md Bayzidur Rahman[A]

[A]The Kirby Institute, Faculty of Medicine and Health, University of New South Wales, NSW, Australia
[B]Sydney Water Corporation, Parramatta, NSW, Australia
[C]Centre for Economic Impacts of Genomic Medicine, Macquarie Business School, Macquarie University, NSW, Australia
[D]NSW Health, Sydney, NSW, Australia
[E]School of Public Health, Faculty of Medicine, University of Queensland, Qld, Australia
[F]School of Population Health, Faculty of Medicine and Health, University of New South Wales, NSW, Australia
[G]European Centre for Environment and Human Health, University of Exeter, Royal Cornwall Hospital, Truro, UK
[H]Tel.: +61 403 854 950; Email: chris.owens@unswalumni.com

Abstract. In any wastewater recycling scheme, the protection of public health is of primary importance. In Australia, the public health requirements applying to the treatment of recycled water are stringent. They use the Disability-Adjusted Life Year (DALY) metric to set a level of negligible public health risk. The target maximum risk of 10^{-6} DALY per person per year has been adopted in Australian water recycling guidelines since 2006. A key benefit of the DALY approach is its ability to standardise the understanding of risk across disparate areas of public health. To address the key challenge of translating the results of monitoring of microorganisms in the recycled water into this quantitative public health metric, we have developed a novel method. This paper summarises an approach where microbial surrogate organisms indigenous to wastewater are used to measure the efficiency of water recycling treatment processes and estimate public health risk. An example of recent implementation in the Greater Sydney region of Australia is provided.

Received 11 August 2021, accepted 28 August 2021, published online 15 September 2021

Introduction

Large scale water recycling schemes are increasing in importance. Climate change and urbanisation are placing pressure on the continued ability to meet regional water demand through conventional water sources such as lakes and aquifers[1]. Similarly, the global challenges posed by inadequate water supply, sanitation, and hygiene highlight the need to increase safe water recycling practices[2].

Various forms of water recycling are taking place in Australia[3]. The largest scale applications involve domestic wastewater contributed by the public to the sewer. When treated to a high standard, recycled water can be safely used by industry and domestic users. There are many Australian schemes where recycled water is supplied through a network that is entirely separate to the drinking water supply (Figure 1), such as the Rouse Hill scheme in north-west Sydney[4]. Such schemes offset the use of the conventional water sources for non-drinking uses with relatively low human exposure, including garden watering and toilet flushing. There are also schemes that are used to safely augment a drinking water supply, such as the Beenyup scheme in Perth, which injects highly treated water into the water table[5,6]. Doing so replenishes the groundwater that is later treated for drinking.

Water safety planning and the health-based target for pathogen reduction

In the *Australian Guidelines for Water Recycling*, EPHC-NRMMC-AHMC[3] set out a framework for the effective and reliable management of safety of water recycling schemes. The approach is formalised in a 12-element recycled water safety plan. The preparation and implementation of a water safety plan is a key regulatory requirement of water supply authorities across Australia. Similar requirements apply in many international jurisdictions.

In formulating the water safety plan, much attention is paid to the risk posed by enteric pathogens in the untreated source water. This risk defines the types of treatment processes required and how well these processes must perform to protect public health. In Australia, the level of pathogens in recycled water deemed to pose a negligible risk is based on a specified public health measurement (referred to as a 'health-based target'). The target is an upper limit of 10^{-6} DALY

Figure 1. Recycled water used for non-drinking purposes in the Greater Sydney region of Australia.

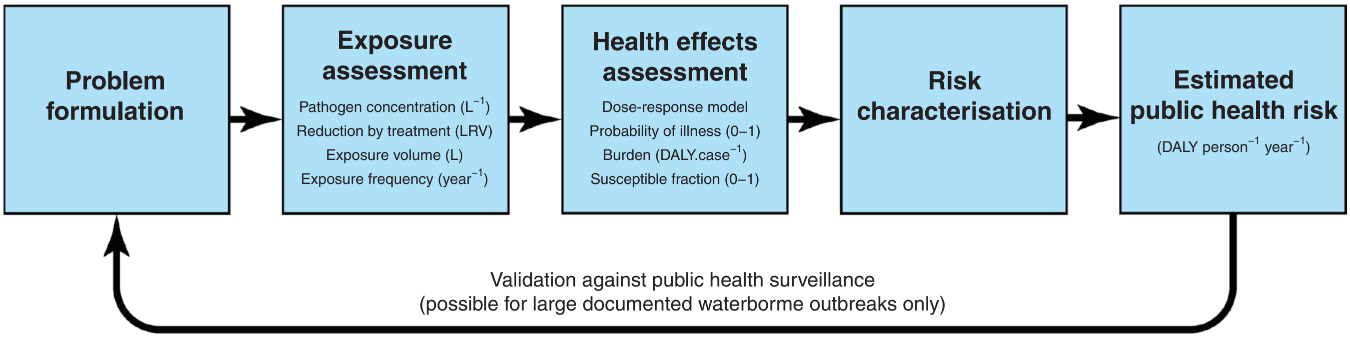

Figure 2. Quantitative microbial risk assessment process.

person per person per year, and it was adopted by the National Health and Medical Research Council over a decade ago[3].

Quantitative microbial risk assessment

When considering the application of the DALY metric to recycled water exposure scenarios, a method is required for translating pathogen levels into public health risk. Quantitative microbial risk assessment (QMRA) is the recognised process to do this[7,8]. It models the nature of exposure, associated health effects, and other relevant factors across a theoretical reference population (Figure 2). Results are then compared to a targeted tolerable (negligible) reference level.

QMRA has been formally embedded in water recycling guidelines in Australia since 2006[3]. It has a much longer history of being used to estimate health risks in drinking water supplies[9,10]. However, novel developments in the approach to implementation are not often presented in literature. The next section of this paper provides a case study of adaptive implementation of the guidelines in the Greater Sydney region of Australia. The approach represents the further development of the method discussed in *Microbiology Australia* by Cox *et al.*[4].

Implementation in the Greater Sydney region of Australia

The case study focuses on a water recycling scheme that supplies to commercial and local government entities. The water is used for purposes categorised as 'municipal irrigation', as defined by EPHC–NRMMC–AHMC[3]. The frequency and volume of public exposure associated with this use are reflected in the required level of pathogen reduction.

The level of pathogen reduction by the wastewater treatment processes was estimated based on monitoring indigenous surrogate organisms representing three major pathogen groups (Table 1) across the treatment process during typical operating

Table 1. Surrogate organisms monitored to understand the fate of each major pathogen group.

Monitored indigenous surrogate	Pathogen group represented	QMRA reference pathogen	Key reference
Escherichia coli	Bacteria	*Campylobacter jejuni*	3
Clostridium perfringens spores	Protozoa	*Cryptosporidium* spp.	3
Bacteriophage MS2	Viruses	Noroviruses (dose-response) Adenoviruses (occurrence)	13
As for protozoa	Helminths	Not used	3

conditions. The surrogates are understood to have similar removal characteristics to their represented pathogens but are generally of higher concentration in domestic wastewater[3,11,12]. The use of surrogates was warranted due to the levels of pathogens in wastewater being too low to fully measure the high level of reduction required. This reflects the stringency of public health requirements and the analytical limitations of detecting pathogens in low concentrations in treated water. The more common approach of challenge-testing the treatment processes was not feasible due to the potential to disrupt the co-located wastewater disposal processes. Similarly, testing during commissioning did not occur due to the original purpose of the plant being for environmental discharge rather than for water recycling.

At the studied water recycling plant, located in Greater Sydney, the microbial surrogates were monitored at three phases: before treatment, following the biological digestion process, and following the chlorination process. A total of 27 samples were analysed over two campaigns, from April 2015 to May 2016 (n = 14) and from April to June 2019 (n = 13). The level of reduction, expressed in terms of the 'logarithmic reduction value' (LRV), was calculated for each treatment process and each pathogen group as $\log_{10}(C_{in}/C_{out})$ (Table 2). C_{in} was the level of surrogate before a treatment process (influent) and C_{out} was the level after (effluent). C_{in} and C_{out} were paired by the date of sampling. Only the results from the latter monitoring campaign were used to assess protozoal removal due to the recent improvement of treatment performance.

Three major steps were involved in determining whether the health-based target was met (Table 3). First, an LRV for each major pathogen group was estimated for the water recycling plant based on the surrogate monitoring results. Because the lower range of performance was of interest, the fifth percentile statistic of the LRV results was used in the subsequent assessment stages (Table 2). Use of the fifth percentile is conservative in comparison to the more common approach of using an average LRV.

The second step was the incorporation of default LRVs associated with end-use limitations, as guided by EPHC-NRMMC-AHMC[3] (Table 3). These limitations seek to reduce exposure of the public to recycled water. They are codified as management practices in the water safety plan.

Table 2. Summary statistics of the daily log-reduction.

Pathogen type/ monitored surrogate	Biological digestion	Chlorination	Full treatment plant
Bacteria (*E. coli*)			
Minimum	2.22	2.39	5.47
Fifth percentile	2.27	3.08	6.07
Median	2.98	4.41	7.26
Mean	2.93	4.13	7.11
Maximum	3.80	5.02	7.82
Viruses (bacteriophage MS2)			
Minimum	–0.41	2.16	3.00
Fifth percentile	0.41	2.42	3.50
Median	1.20	2.96	4.14
Mean	1.14	2.90	4.03
Maximum	2.18	3.41	4.62
Protozoa (*Clostridium perfringens* spores)			
Minimum	1.02	NA	1.02
Fifth percentile	1.30	NA	1.30
Median	1.76	NA	1.76
Mean	1.74	NA	1.74
Maximum	2.25	NA	2.25

Removal of protozoa through chlorination is not applicable (NA) due to their resistance to this disinfectant.

The final step involved the comparison of the aggregated LRVs to the default LRV requirements (Table 3). The default LRV requirements were taken from the draft revised *Australian Guidelines for Water Recycling*[13], rather than the current version, for two reasons. First, the revised guidance recognises the decreased incidence and burden of rotavirus infection following the recent implementation of broad community vaccination[13–15]. Second, newer literature relevant to the selection of dose-response models and other assessment

Table 3. Aggregated assessment of pathogen reduction requirements.

Log-reduction value (LRV) type	Notation	LRV			Derivation
		Bacteria	Viruses	Protozoa	
Fifth-percentile total verified treatment reduction	LRV_{P5}	6.07	3.50	1.50	Table 2
Exposure-reduction adjustment: restricted public access during irrigation	E_1	2.00	2.00	2.00	[3]
Exposure-reduction adjustment: spray-drift controls	E_2	1.00	1.00	1.00	[3]
Total scheme LRV claimed		**9.07**	**6.50**	**4.50**	$LRV_{P5}+E_1+E_2$
Required scheme LRV		*4.70*	*5.0*	*4.40*	[13]

assumptions are incorporated[13]. The health-based target was considered met if the aggregated LRV for each pathogen type was greater than or equal to the relevant LRV requirement.

Using the microbial surrogate data and the above method, the recycling scheme was shown to meet the public health requirements for waterborne enteric pathogens (Table 3). The key benefit of the surrogate monitoring approach is its ability to overcome the described limitations inherent to operational water recycling schemes when assessing public health requirements. The approach complements existing methods for the assurance of safe water recycling. Overall, it is crucial that QMRA implementation is subject to ongoing critical evaluation, adapts to new evidence, and incorporates conservative assumptions where appropriate.

Conflicts of interest

The authors declare no conflicts of interest.

Declaration of funding

This research did not receive any specific funding.

Acknowledgements

Sydney Water is acknowledged for allowing the secondary analysis of its data.

References

1. Chen, Z. *et al*. (2013) A critical review on the end uses of recycled water. *Crit. Rev. Environ. Sci. Technol.* **43**, 1446–1516. doi:10.1080/10643389.2011.647788
2. UN (2017) Resolution Adopted by the General Assembly on 6 July 2017: Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development (A/RES/71/313) United Nations.
3. EPHC-NRMMC-AHMC (2006) Australian Guidelines for Water Recycling: Managing Health and Environmental Risks Phase 1. Environment Protection and Heritage Council, Natural Resource Management Ministerial Council, Australian Health Ministers Conference. https://www.waterquality.gov.au/guidelines/recycled-water
4. Cox, P. *et al*. (2009) Meeting the recycled water challenge for Sydney. *Microbiol. Aust.* **30**, 23–26. doi:10.1071/MA09022
5. WRA (2019) Potable Water Reuse: What Can Australia Learn From Global Experience? Water Research Australia.
6. WHO (2017) Potable Reuse: Guidance for Producing Safe Drinking-water. World Health Organization.
7. WHO (2016) Quantitative Microbial Risk Assessment: Application for Water Safety Management. World Health Organization.
8. WHO (2016) Sanitation Safety Planning: Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta. World Health Organization.
9. Owens, C.E.L. *et al*. (2020) Implementation of quantitative microbial risk assessment (QMRA) for public drinking water supplies: systematic review. *Water Res.* **174**, 115614. doi:10.1016/j.watres.2020.115614
10. Owens, C.E.L. *et al*. (2017) Microbial health-based targets for drinking water: current state and Australian case study. *Microbiol. Aust.* **38**, 196–198. doi:10.1071/MA17068
11. Keegan, A. *et al*. (2009) Pathogen Risk Indicators for Wastewater and Biosolids. IWA Publishing.
12. Keegan, A. *et al*. (2009) Pathogens and indicators in wastewater matrices. *Microbiol. Aust.* **30**, 8–11. doi:10.1071/MA09008
13. EPHC-NRMMC-AHMC (2017) Australian Guidelines for Water Recycling: Managing Health and Environmental Risks Phase 1 2017 Draft. Environment Protection and Heritage Council, Natural Resource Management Ministerial Council, Australian Health Ministers Conference.
14. Ward, K. *et al*. (2011) Evaluation of the National Rotavirus Immunisation Program: Final Report. National Centre for Immunisation Research and Surveillance.
15. Gibney, K.B. *et al*. (2014) Disease burden of selected gastrointestinal pathogens in Australia, 2010. *Int. J. Infect. Dis.* **28**, 176–185. doi:10.1016/j.ijid.2014.08.006

Biographies

Dr Christopher Owens is a recent doctoral graduate from the University of New South Wales. This paper stemmed from his doctoral research and his prior professional work as a Senior Analyst in public health at Sydney Water. He is currently a Research Fellow at the Centre for Economic Impacts of Genomic Medicine at Macquarie University.

Dr Peter Cox is the Water Quality Lead at Sydney Water and is the workplace supervisor for this research.

Dr Paul Byleveld is the Manager of the Water Unit at NSW Health and is an academic co-supervisor of this research.

Associate Professor Nicholas Osborne is principally affiliated with the School of Public Health, University of Queensland, and is an academic co-supervisor of this research.

Dr Md Bayzidur Rahman is a Senior Lecturer at The Kirby Institute, University of New South Wales, and is the principal academic supervisor of this research.