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REVIEW OF QUANTITATIVE MICROBIOLOGICAL RISK ASSESSMENT (QMRA) FOR THE PŌRANGAHAU WASTEWATER TREATMENT PLANT DISCHARGE

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1. BACKGROUND

Hawkes Bay Regional Council (HBRC) have contracted the Institute of Environmental Science and Research Limited (ESR) to provide technical peer review of a quantitative microbial risk assessment (QMRA) (Dada, 2022) related to an application for resource consent renewal for the Pōrangahau wastewater treatment plant (WWTP) discharge.

1.1 TERMINOLOGY

Risk assessments, including QMRA, should include an appropriate level of conservativism. In this context, a conservative assumption is one that errs on the side of caution. Input parameters should be sufficiently conservative for the risk assessment to encompass all realistic scenarios. Conservative approaches ensure that decisions made, based on the risk assessment, will be protective of public health.

At the same time, risk assessments should not be overly conservative. An overly conservative risk assessment model would include scenarios that are unrealistic and, while decisions based on such a risk assessment would be protective, the risk assessment outputs may constrain risk management.

The assumptions used in the Pōrangahau WWTP QMRA were examined to determine if they are insufficiently, sufficiently or overly conservative.

2. QUANTITATIVE MICROBIOLOGICAL RISK ASSESSMENT (QMRA)

The QMRA conducted by QMRA Data Experts considered discharge of treated wastewater into the Pōrangahau River approximately 600 m downstream of the Pōrangahau township and 10 km upstream of the river's discharge into the Pacific Ocean (Dada, 2022). The QMRA assessed risks to human health from:

- Recreational water use in the area affected by the wastewater discharge
- Consumption of raw shellfish from the area affected by the wastewater discharge.

Outputs from the QMRA were expressed as individual illness risk (IIR) and included scenarios covering:

- Pathogens (3 viruses; adenovirus, enterovirus and norovirus)
- Locations (4 locations between the WWTP discharge point and the river mouth)
- Pathogen removal (3 scenarios; current, current plus UV treatment and a 5% run-off from future land application of the effluent)

The following sections will consider the appropriateness of the selected scenarios, the pathogen concentration data used, the input parameters used for exposure modelling, the dose-response relationships used to determine the IIRs from the exposure estimates and the benchmark risk levels used to characterise the IIRs.

While not of technical importance, the review and release date for the QMRA report (p2) are in the future and should be corrected.

2.1 SELECTION OF PATHOGENS

Domestic wastewater may contain a range of bacterial, viral, protozoal and helminth pathogens. The authors of the QMRA selected three viral species (adenovirus, enterovirus and norovirus) as the basis for the QMRA. The selection of these viral pathogens is likely to be appropriate, although no information specific to the Pōrangahau WWTP was presented to support the selection of these viral pathogens.

2.2 PREDICTED CONCENTRATION OF VIRUSES IN WATER

Four sites were selected to assess risks associated with recreational water contact, with one site (site 4) also used to assess risks associated with harvesting of shellfish for raw consumption. The process for selecting the sites was not described but the selected sites appear suitable.

Influent concentrations of norovirus, enterovirus and adenovirus were taken verbatim from studies by McBride (McBride, 2016; McBride and Hudson, 2016) and represented by custom distributions (hockey stick) to include less common, very high viral concentrations observed in one study (the Mangere scoping study (DRG, 2002)). The very high concentrations of adenovirus and enterovirus seen in the Mangere scoping study have not been subsequently reported in any New Zealand or international studies and these results should be viewed as being questionable. The use of these data for the Pōrangahau WWTP QMRA is potentially overly conservative.

The impact of the wastewater treatment plant on viral concentrations was modelled in terms of three scenarios covering combination of the current treatment (oxidation pond) and the potential addition of UV treatment. The viral removals by the processes were reported to be

based on a literature review carried out by Beca. The literature review was not provided or summarised. The mean log reductions used in the QMRA model were 1 $\log_{10}$ removal for all virus types due to the oxidation pond and additional mean reductions of 3.4 and 2.5 $\log_{10}$ for norovirus and enterovirus, respectively, due to UV treatment (Appendix 1). Additional log removal of adenovirus is not reported in Appendix 1, but according to Figure 4 appears to be minimal.

These viral log removals appear very high, based on our own review of the literature. Studies on norovirus inactivation by UV treatment typical show removals of less than 1 $\log_{10}$ (Barrett *et al.*, 2016; Campos *et al.*, 2016; Qiu *et al.*, 2015; Qiu *et al.*, 2018; Simhon *et al.*, 2020). While less information is available for enteroviruses and adenoviruses, inactivation by UV treatment appears to be similarly low (<1 $\log_{10}$) (Qiu *et al.*, 2015; Qiu *et al.*, 2018). Unless information is provided to substantiate the log removal figures used in the QMRA then the results of scenarios based on UV treatment should be viewed with caution.

Estimates of the degree of dilution of discharged effluent in the Pōrangahau River were reported to be derived from a dye mixing study conducted by Beca in 2009. This study estimated dilutions of 1000-3000 in the mixing zone immediately downstream of the discharge point. The author of the QMRA then used a log ratio approach to calculate dilutions at locations further downstream. The basis for the equations used is not referenced.

Given that QMRA models generally assume a constant continuous discharge of effluent, increased dilution in the lower reaches of the Pōrangahau River would be dependent in flow increases from streams joining the river or tidal action. NIWA's New Zealand river maps (https://shiny.niwa.co.nz/nzrivermaps/) reports a mean flow for the Pōrangahau River of 10.3 cumecs near to the site of the WWTP, about 11.9 cumecs near site 3 and the same near site 4. These flows do not suggest that there are major additions of freshwater to the Pōrangahau River between the WWTP and the river mouth. Further information should be supplied to substantiate the >4-fold modelled increase in dilution through this stretch of the river.

The QMRA appears to have discounted the potential impact of river low flow situations. The NIWA resource indicates that mean annual low flows in the Pōrangahau River are substantially below mean flows (<0.5 cumecs). While the QMRA states that "tidal interchange in this section of the river is more significant in the context of the wastewater discharge than the base river flow" (P17), this statement is not supported by objective data or hydrodynamic modelling.

While it is likely that the QMRA is correct in asserting that dilution of effluent in the Pōrangahau River will be substantially affected by tidal action, the assessment should be as quantitatively accurate as possible and would benefit from an associated hydrodynamic model to predict dilutions at the assessment sites.

2.3 ROUTES OF EXPOSURE

The QMRA considered three potential routes of exposure:

- Oral exposure due to water ingested during primary contact recreation (swimming)
- Oral exposure due to consumption of contaminated raw shellfish
- Respiratory exposure due to intake of water aerosolised during contact recreation, such as surfing or waterskiing.

Swimming is the most common aquatic contact recreation activity for New Zealanders (Moran, 2008; 2009; Sport New Zealand, 2012; 2015) and is an appropriate 'sentinel activity' for risk assessment in this context. Similarly, the ability of bivalve molluscan shellfish to

bioaccumulate viruses and the fact that shellfish may be eaten raw (no thermal kill step for viral pathogens) makes this exposure route a suitably conservative (risk maximising) choice for the current QMRA.

Respiratory exposure is likely to be a lesser route of exposure than oral exposure from swimming and shellfish consumption but is better aligned with the normal route of infection for adenovirus.

2.4 EXPOSURE MODEL – SWIMMING

2.4.1 Duration of swimming

The QMRA uses data from a Dutch study on the duration of swimming events (Schets *et al.*, 2011). While these data are not for a New Zealand population, they provide a suitably objective basis for the duration of swimming.

2.4.2 Water ingested per swimming event

Data on water ingestion were reported as taken from the study of Dufour et al. (2017), as reported by Cressey (2020). The author of the current QMRA commented that the combination of swimming duration from Schets et al. (2011) and the water ingestion rates from Dufour et al. (2017) could result in very high estimates of the amount of water ingested and truncated the combined distribution of the duration and ingestion rate at 279 mL, the maximum reported by Dufour et al. (2017). This decision was based on an assertion that "it may be unrealistic for swimmers to ingest a litre of water during swimming". This appears to be the authors opinion and the introduction to Dufour et al. (2017) identifies studies that measured ingestion of up to 800 mL of water by competitive swimmers.

It should be noted that, in the study of Dufour et al. (2017) participants were instructed to swim for approximately one hour. While children participating in the study generally swam for longer, it is questionable whether a maximum ingested volume from a controlled and constrained study should be applied to free-living populations.

2.5 EXPOSURE MODEL – INHALATION

Little information is available on the amounts of water inhaled during secondary contact aquatic recreation. The QMRA referenced the study of Rice et al. (2012) and doubled the estimates derived in that study. The inhaled volumes used in the QMRA (minimum 0.4 mL/hr, maximum 4 mL/hour) appear more realistic than figures used in previous QMRAs. As a point of comparison studies of water ingestion during secondary recreation have commonly reported ingestion amounts of 'one or two drops' and 'a teaspoon or more' (Dorevitch *et al.*, 2011; Murray *et al.*, 2015). Although ingestion and inhalation are different exposure routes there are likely to be some similarities in exposure volumes in secondary recreational circumstances.

2.6 EXPOSURE MODEL – SHELLFISH CONSUMPTION

The shellfish consumption exposure model assumes bioaccumulation of viruses from the water column by bivalve molluscan shellfish.

2.6.1 Shellfish serving size

Shellfish serving size distributions were based on 24-hour dietary recall information from the 1997 National Nutrition Survey (Russell *et al.*, 1999). While these data have been superseded by those from the 2008-2009 Adult Nutrition Survey (University of Otago and Ministry of Health, 2011), the data from the 1997 National Nutrition Survey are still suitable for acute (single serving) dietary exposure assessment.

It should be noted that the QMRA suggests that there is a Ministry for Primary Industries warning against the consumption of raw shellfish (p34). This warning related specifically to circumstances related to an outbreak of *Vibrio parahaemolyticus* infections associated with

shellfish from the Coromandel and is not a generalised warning against the consumption of raw shellfish.

2.6.2 Bioaccumulation factor

The same bioaccumulation factor was used for all three viruses and was derived from studies on a surrogate virus, F^+ coliphage (Burkhardt and Calci, 2000). While more recent and specific studies on the bioaccumulation of norovirus by shellfish have been published (Drouaz *et al.*, 2015; Maalouf *et al.*, 2011), they do not provide suitable bioaccumulation factors and the factors from the study of Burkhardt and Calci (2000) appears suitable for the current QMRA.

2.7 DOSE-RESPONSE RELATIONSHIPS

Dose-response relationships are generally derived from rare human volunteer studies and dose-response models are usually fairly consistent across different QMRA. The current QMRA references other QMRAs that have used the selected dose-response models but does not reference the source studies.

The current QMRA uses the following dose-response models:

- Adenovirus. Although not specifically stated, the infection dose-response relationship for adenovirus is derived from the study of Couch et al. (1969). This is the dose-response relationship usually used for environmental QMRA. A value of 50% was used for the probability of illness, given infection. This value was used in an influential US study (Soller *et al.*, 2010) and is consistent with proposals by the World Health Organization to use 50% as the probability of illness, given infection, for viruses, in the absence of specific information.

- Enterovirus. The dose-response relationship for enterovirus is derived from a clinical study on echovirus, a member of the enterovirus group. The current QMRA has used a range of values for the probability of illness given infection of 0.24-0.57, from the study of Moazeni et al. (2017). In other New Zealand QMRAs, a conservative approach has also been adopted by assuming that 100% of enterovirus infections will result in illness. However, the range used for the current QMRA encompasses proposals by the World Health Organization to use 50% as the probability of illness, given infection, for viruses, in the absence of specific information.

- Norovirus. The QMRA uses a dose-response model for norovirus derived by Teunis et al. (2008). This is the model most commonly used for environmental QMRA. The probability of illness, given infection (60%), has been used in other environmental QMRA (Soller *et al.*, 2010) and appears appropriate.

The dose-response relationships and probabilities of illness used in the QMRA are those commonly used in environmental QMRA internationally.

2.8 PRESENTATION OF RISK ESTIMATES

The QMRA assesses risks in terms of individual illness risk (IIR).

The IIR estimates are compared to risk categories in the *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas* (MfE, 2003). The categories are derived from the guideline values for microbiological quality of **marine** recreational waters. Given that the assessment sites are all within the Pōrangahau River, it is uncertain why the author of the QMRA selected the marine categories, rather than the freshwater categories from the same MfE document. The QMRA stated that this decision was due to the fact that "this stretch of river is dominated by tidal influences with generally low baseflow" (p32).

It should be noted that the MfE guidelines for freshwater have been replaced by the *National Policy Statement for Freshwater Management* (NSP) (New Zealand Government, 2020). The attribute bands from this document are shown in Table 1. The NSP is applicable to all freshwater (including groundwater) and, to the extent they are affected by freshwater, to receiving environments (which may include estuaries and the wider coastal marine area). On this basis, the NSP appears to be the appropriate reference for assessing IIRs from the current QMRA.

Table 1. Attribute bands for primary human contact with freshwater and costal receiving waters

Attribute band	Description
Excellent	<0.1% infection risk 95% of the time
Good	0.1 - 1% infection risk 95% of the time
Fair	1 - 5% infection risk 95% of the time
Poor	>5% infection risk at least 5% of the time

Source: New Zealand Government (2020), Table 22

3. CONCLUSIONS

The QMRA conducted to assess the risks of human illness due to the Pōrangahau WWTP discharge uses currently accepted methodology for assessments of this sort. However, there are several aspects of the QMRA that require further elaboration to justify the decisions made in the formulation of the model. These are:

- The derivation of log removal values for the application of UV treatment
- The derivation of dilution estimates for sites 2-4
- The use of marine microbiological guidelines, rather than the freshwater NPS for assessment of the risks.

All of these decisions have the potential to result in under-estimation of the risks associated with the Pōrangahau WWTP discharge and, in combination, the degree of under-estimation may be considerable.

This leaves the current case (oxidation pond) at site 1 as an assessment of risk that should be reliable. The mean IIR at this site for norovirus or enterovirus would result in a classification of the river being fair with respect to bathing quality, according to the NPS. This conclusion refers only to the expected contamination of the environment due to discharges from the Pōrangahau WWTP. The Land, Air and Water Aotearoa (LAWA) resource[1] provides information on the microbial quality of the Pōrangahau River at Pōrangahau Road, upstream of the WWTP and swimming water quality at the Estuary Bridge (Site 3 of the QMRA). Both of these indicators suggest that quality of the Pōrangahau River for contact or swimming is low.

[1] https://www.lawa.org.nz/ Accessed 23 February 2022

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