QMRA DATA EXPERTS

Quantitative Microbial Risk Assessment (QMRA) of the Pōrangahau Wastewater Treatment Plant discharge

January 2022

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Report QDE – Pōrangahau 2022

Prepared for Beca Ltd (Beca) & Lowe Environmental Impact Ltd (LEI) on behalf of Central Hawkes Bay District Council (CHBDC)

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Executive Summary

Central Hawkes Bay District Council (CHBDC) is seeking renewal of consents to discharge treated wastewater into the Pōrangahau River, as an interim measure, before switching to an alternative land-based discharge option.

Currently, the Pōrangahau WWTP discharges to the Pōrangahau River while the Te Paerahi WWTP discharges to coastal dunes in a narrow spit of land located between the Pōrangahau River and the Pacific Ocean. A proposed wastewater scheme will divert treated wastewater generated from the Pōrangahau and Te Paerahi communities, progressively, to an identified area of farmland, located between the two WWTPs. The future discharge option will also have additional ultraviolet (UV) disinfection. The UV-disinfected wastewater will travel through soils and any bacteria remaining within the treated wastewater will be further filtered, predated upon (by soil microorganisms) and die-off, prior to being discharged into surface waterways. No additional adverse loading of bacteria concentrations is therefore expected from the new wastewater scheme.

The baseline discharge conditions will, however, continue for the initial period of the short-term consent duration (up to four years at Te Paerahi and six years at Pōrangahau from consent being granted while the new land-treatment stages are developed). As direct discharge into the Pōrangahau River will gradually cease, it is anticipated that future discharge will be an improvement upon existing conditions. However, a quantitative microbial risks assessment is required to demonstrate that the current discharge, which will continue for the next six years, does not pose a threat to public health, in relation to shellfish gathering and primary recreation.

QMRA Data Experts (QDE) have therefore been engaged to undertake a Quantitative Microbial Risk Assessment (QMRA). The QMRA assesses the viral enteric illness risks related to primary and secondary contact recreation, as well as risks related to consumption of harvested shellfish harvested in the receiving environment following discharge from the Pōrangahau WWTP.

The project proceeded in the following phases.

- Estimates of the range of dilution likely to occur in the receiving water at sites of interest were provided by BECA Ltd, based on a previous mixing study (Opus, 2009[1]).
- Completion of a quantitative microbial risk assessment modeling (QMRA) that focused on reference pathogenic viruses that are (a) relevant to human health, (b) have established dose-response functions (norovirus and enterovirus, and (c) have been applied in several previous NZ QMRAs for environmental waters impacted by treated wastewater. Typical concentrations of these viruses in untreated wastewater, as documented in previous New Zealand QMRAs, were used to assess risks associated with ingestion/inhalation of potentially

[1]Pōrangahau Township Oxidation Pond Discharge Mixing Study (2009) by Opus

polluted water or ingestion of potentially contaminated shellfish harvested from the receiving environment.

- Risk profiles were compared with guidelines established in the New Zealand "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*" (MfE/MoH 2003): that is, high illness risk (>10% gastrointestinal (GI) illness); moderate illness risk (5-10% GI illness); low illness risk (1-5% GI illness); and the "no observable adverse effects level" (<1%). These thresholds have been applied in several previous NZ QMRAs for environmental waters impacted by treated wastewater

In order to optimize public health protection, this QMRA applied a precautionary approach throughout the modelling; for instance,

- by the inclusion of occasional very high influent virus concentrations that may occur during on-going but undetected viral illness outbreak in the community.
- by assuming no microbial inactivation occurs due to solar radiation in the receiving environment following discharge, despite documented literature that indicates that sunlight-based ultraviolet inactivation may occur in the receiving environment.
- by reporting children's recreational illness risk as opposed to the generally lower adults' risk based on the assumption that children typically spend about twice as much time in the water than adults (e.g. Dufour et al.2006, 2017);
- by assuming that shellfish gathered in the receiving environment would be consumed raw, contrary to MPI's warnings that advice members of the public to cook shellfish before consumption[2].
- by applying higher water inhalation rates than was previously reported in international studies (e.g. Rice et al 2012) for moderate intensity of activity.

This highly conservative stance may mean that risks profiles reported in this report are over-estimated.

In consultation with Beca, LEI and CHBDC, 4 key exposure sites (Sites 1-4) were identified in the Pōrangahau River and estuary receiving environment. These sites could be potentially impacted because of wastewater discharge.

- Site 1, at the edge of the mixing zone and approximately 200m downstream of the Pōrangahau WWTP discharge;
- Site 2, a fishing area, approximately 3km downstream of the current discharge site);
- Site 3, at the bridge with access site to river, approximately 4km downstream of the current discharge site and,
- Site 4, a shellfish gathering site, approximately 7km downstream of the current discharge site.

[2] MPI encourages all to avoid eating raw shellfish. "Don't eat raw or undercooked mussels or other shellfish. Cook them before eating.". Available online at: https://www.mpi.govt.nz/news/media-releases/food-poisoning-associated-with-consumption-of-raw-mussels/

Summary of QMRA Results: Risk associated with primary contact recreation(e.g. swimming)

During current treatment and discharge conditions, predicted individual illness risks (IIR) associated with swimming were generally low, and ranged from 0.548% to 1.642%. Predicted IIRs were 1.642% and 1.126%, respectively at Site 1 (200m downstream of the current discharge) and Site 2 (fishing area, approximately 3km downstream of the current discharge site). Although these predicted IIRs at Site 1 and Site 2 exceed the 1% IIR threshold for "no observable adverse effects level" (NOAEL), it is important to emphasize that Site 1 is very close to the discharge and is not accessible to the public. While Site 2 may be accessible to the public for fishing, it is not certain that it is used for swimming, other than occasional partial body immersion to collect fish. However, there is public access at Site 3, i.e., the bridge approximately 4km downstream of the current discharge site. Predicted IIR (0.946%) at this site is already at the brink of exceeding the 1% NOAEL threshold. <u>These results indicate a low human health risk associated with swimming due to the discharge from the pond-treated Pōrangahau WWTP.</u>

However, before the new land-based WWTP is implemented, if in the interim, Pond+UV treatment were to be applied to the current WW flow discharged into Pōrangahau River over the next six years, the improved treatment would reduce swimming-related health risk below the NOAEL at all sites.

The proposed future land treatment system is designed to avoid overland flow. Notwithstanding this design, using a precautionary worst-case approach that assumes 5% of land applied UV-treated wastewater reaches Pōrangahau River (ignoring any land-based pathogen attenuation), predicted health risks would fall below the NOAEL at all sites. Additionally, this scenario presents with the lowest IIR profiles among the three considered discharge options.

Summary of QMRA Results: Risk associated with secondary contact recreation (e.g. kayaking)

During current treatment and discharge conditions, individual illness risks associated with aerosol inhalation[3] was predicted to be low at Site 1 (IIR = 0.38%), equivalent to an average probability of 3.8 acute respiratory illness cases per 1000 exposures. The predicted IIR at Site 1 was marginally higher than the IIR threshold of 0.3% "no observable adverse effects level" threshold. These results indicate a low acute febrile respiratory illness risk associated with exposure to aerosols at Site 1, 200 m downstream of the discharge. It is important to note that public access to this site is restricted, hence predicted low risks are conservative. At other sites further

[3] During boating, kayaking and other activities that may expose individuals to inhalation of aerosols

downstream (i.e. Sites 2, 3 and 4), predicted IIR are 0.184%, 0.138% and 0.097%, respectively. These predicted IIRs fall below the "no observable adverse effects level".

However, before the new land-based WWTP is implemented, if in the interim, Pond+UV treatment were to be applied to the current WW flow discharged into Pōrangahau River over the next six years, the improved treatment would reduce acute respiratory illness risk below the NOAEL at all sites.

Using a precautionary worst case that assumes 5% of land applied UV-treated wastewater reaches Pōrangahau River (ignoring any land-based pathogen attenuation), it is predicted that acute respiratory health risk would fall below the NOAEL at all sites following the implementation of the proposed future land treatment system. Additionally, this scenario has the lowest IIR profiles of the three considered discharge options.

Summary of QMRA Results: Risk associated with consumption of raw shellfish

During current pond-based treatment and discharge conditions, when norovirus was used as the reference QMRA pathogen, predicted individual illness risk (IIR) was 5.68% at Site 4 where shellfish gathering occurs/potentially occurs. The QMRA results therefore predict moderate health risks as a result of consuming raw shellfish harvested at Site 4.

However, if in the interim, UV treatment is applied to the current pond discharge into the Pōrangahau River, the improved treatment will reduce shellfish consumption-related health risk below the NOAEL at all sites. This assessment assumes the continuous discharge of treated wastewater to the Pōrangahau River and does not assess the potential benefits of the staged removal of wastewater as part of the transition to discharge to land.

Future land discharge with improved treatment will reduce health risk below the NOAEL at this site.

1. Introduction

Central Hawkes Bay District Council (CHBDC) is seeking renewal of consents to continue discharging treated wastewater into the Pōrangahau River, in the interim, before switching to an alternative land-based discharge option.

Two wastewater treatment plant currently services Pōrangahau and Te Paerahi communities. Based on the provisions of a previously granted consent (No. DP030233W)[4], the Pōrangahau WWTP treats wastewater[5] from the Pōrangahau community (approx. 97 households) using a single oxidation pond before discharging to a small farm drain that ultimately flows into the Pōrangahau River approximately 600 m downstream of the Pōrangahau Township, and about 10 km upstream of the river's discharge to the Pacific Ocean. Historical reports indicate this stretch of river is dominated by tidal influences with generally low baseflow (Beca, 2021).

The Te Paerahi WWTP (first established in the 1990s) treats wastewater[6] from the Te Paerahi community (which is largely a holiday destination) using a single clay lined oxidation pond. A proposed wastewater scheme will divert treated wastewater generated from the, Pōrangahau and Te Paerahi communities, progressively, to an identified area of farmland, located in between the two WWTPs. The future discharge option will also have ultraviolet (UV) disinfection. The UV-disinfected wastewater will travel through soils and any bacteria remaining within the treated wastewater will be further filtered, predated upon (by soil microorganisms) and die-off, prior to being discharged into surface waterways. No additional adverse loading of bacteria concentrations is therefore expected from the new wastewater scheme.

The baseline discharge conditions will, however, continue for the period of the short-term consent duration (up to four years at Te Paerahi and six years at Porangahau while the subsequent stages are enacted). As direct discharge into the Pōrangahau River and Estuary will gradually cease, it is anticipated that future discharge will be an improvement upon existing conditions. However, a quantitative microbial risks assessment is required to demonstrate that the current discharge, which will continue for the next six years, does not pose a threat to public health, in relation to shellfish gathering and primary recreation. This was the main concern identified during the review of the discharge consent application. Beca Ltd (Beca) & Lowe Environmental Impact Ltd (LEI) on behalf of Central Hawkes Bay District Council (CHBDC) therefore require a Quantitative Microbiological Risk Assessment (QMRA) to address S92 comments in relation to Pōrangahau and Te Paerahi Wastewater Treatment Plants (WWTP) discharge consent application. The S92 query is as below:

[4] Hawke's Bay Regional Council granted the resource consent on the 22nd of October 2009, expired 31 May 2021
[5] Pōrangahau WWTP Median average daily flow (ADF) =130 m^3/day, 95th Perc. ADF= 415 m^3/day
[6] Te Paerahi WWTP Median average daily flow (ADF) =87 m^3/day, 95th Perc. ADF= 190 m^3/day

> Please provide a quantitative microbial risk assessment (QMRA), in accordance with the Ministry of Health's microbial guidelines and/or the relevant best practice guidelines, on the potential health risks to users of Pōrangahau River. Technically robust information must be provided as part of the assessment including appropriately detailed approaches to how the risks will be mitigated.

QMRA Data Experts (QDE) have therefore been engaged to undertake a Quantitative Microbial Risk Assessment (QMRA). The QMRA assesses the viral enteric illness risks related to primary contact recreation and consumption of harvested shellfish harvested in the receiving environment following discharge from Pōrangahau WWTP.

The project proceeded in the following phases.

- Estimates of the range of dilution likely to occur in the receiving water at sites of interest were provided by BECA Ltd, based on a previous mixing study (Opus 2009).
- Completion of quantitative microbial risk assessment modeling (QMRA) that focused on reference pathogenic viruses that are (a) relevant to human health, (b) have established dose-response functions (norovirus, adenovirus and enterovirus, and (c) have been applied in several previous NZ QMRAs for environmental waters impacted by treated wastewater. Typical concentrations of these viruses in untreated wastewater, as documented in previous New Zealand QMRAs[7], were used to assess risks associated with ingestion/inhalation of potentially polluted water or ingestion of potentially contaminated shellfish harvested from the receiving environment.
- Risk profiles were compared with guidelines established in the New Zealand "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*" (MfE/MoH 2003): that is, high illness risk (>10% gastrointestinal (GI) illness); moderate illness risk (5-10% GI illness); low illness risk (1-5% GI illness); and the "no observable adverse effects level" (<1%). These thresholds have been applied in several previous NZ QMRAs for environmental waters impacted by treated wastewater

Following this introductory section, Sections 2 and 3 present the methodology and discuss the results of the quantitative microbial risk assessment modeling (QMRA), covering health risks associated with swimming and consumption of raw shellfish harvested from the receiving environment. A conclusion is presented in Section 4.

[7] Oldman and Dada (2020), Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al. 2017,

2. Quantitative Microbial Risk Assessment (QMRA)

2.1 Overview

A Quantitative Microbial Risk Assessment (QMRA) is a framework that applies information and data incorporated into mathematical models to assess the potential public health risks from pathogens after discharge into a receiving environment such as water[8]. While quantitative risk assessment was initially designed to assess risks of exposure to various hazards, particularly chemicals, it has since been modified to incorporate risks related to exposure to microbial pathogens (NRC 1983). Risk is the combination of the likelihood of identified hazards causing harm in exposed populations in a specified time frame and the severity of the consequences (Hrudey, Hrudey, and Pollard 2006).

Typically, a QMRA includes various stages of hazard identification, exposure assessment, dose-response analysis, and risk characterization (Dada & Pradip 2022, Haas, Rose, and Gerba 1999). These stages are graphically represented in Figure 1.

2.2 Hazard analysis

Wastewater may contain several pathogenic species (Jacangelo et al. 2003; McBride 2007). The majority of pathogens in wastewater are enteric; that is, they affect the digestive system, and may present a serious health risk if ingested (Hai et al. 2014). These pathogens include: protozoans, which can cause life-threatening diseases including giardiasis, cryptosporidiosis, dysentery and amoebic meningoencephalitis (Bitton 2010); viruses, which can cause paralysis, meningitis, respiratory disease, encephalitis, congenital heart anomalies and upper respiratory and gastrointestinal illness (Melnick, Gerba, and Wallis 1978; Toze 1997; Okoh, Sibanda, and Gusha 2010); and bacteria, consisting of the enteropathogenic and opportunistic bacteria which cause gastrointestinal diseases such as cholera, dysentery, salmonellosis, typhoid and paratyphoid fever (Toze 1997; Cabral 2010).

Because the tests for pathogens are time-consuming and expensive, it is not practical to implement such testing on a routine basis. Instead, regulatory bodies support testing for faecal indicator bacteria (FIB) (e.g. enterococci and faecal coliforms) as a cost-effective means to assessing the presence of faecal contamination and the quality of treated effluent. These generally non-pathogenic bacteria are contained in the gut of warm-blooded animals, including humans, in large concentrations. Research shows that most pathogens die at the same rate as FIB, and hence the numbers of FIB in the treated effluent can be used to indicate the presence of pathogens.

While focus has been placed on *E.coli*[9] and *enterococci*[10] concentrations for regulatory purposes, limitations associated with the use of conventional FIB as an indicator for viruses is well documented, particularly in relation to the poor correlation of FIB and

[8] It is important to note that the assessment only relates to the risk from a particular discharge, i.e. it doesn't take into account the risks associated with other discharges (for example, stormwater or non-point source discharges) that may be in the area.
[9] in freshwater
[10] in marine water

viruses (Wade et al. 2008, Wade et al. 2010, USEPA 2015). Furthermore, as most standard wastewater treatment and disinfection processes vary in their efficiency in eliminating viruses, treated effluent may still contain concentrations of enteric viruses that present a significant public health risk (Lodder et al. 2010; Okoh, Sibanda, and Gusha 2010). Several enteric viruses have been described in published literature as associated with outbreaks due to exposure to polluted recreational water (Jiang et al., 2007; Sinclair et al., 2009, USEPA 2015). These include noroviruses, adenoviruses, hepatitis A viruses, echoviruses and Coxsackie viruses (Hauri et al. 2005; Lodder et al. 2010). Literature has also suggested that the greatest public health risk linked with the discharge of treated wastewater relates mainly to viruses (Courault et al. 2017; Prevost et al. 2015). A unique characteristic of viral infections is that a high proportion of the exposed populations could be potentially affected, often leading to very high incidences of gastroenteritis and respiratory illnesses that can then be spread by person-to-person contact to other individuals who were not directly exposed to the polluted waters (Patel et al. 2008; Widdowson, Monroe, and Glass 2005). For instance, a single vomiting incident from an individual infected with norovirus could expel up to 30 million virus particles (Tung-Thompson et al. 2015). In community settings, this could result in contamination of surfaces with large numbers of viruses, effectively promoting the further spread of the pathogens.

Given risks associated with human exposure to viruses in aquatic environments receiving wastewater discharge and the lack of meaningful correlations between FIBs and viruses, existing approaches that are reliant on FIB concentrations are not sufficient to address health risks. The QMRA is considered the "best practice" for health risks assessment of waters impacted by wastewater discharge (Crawford, McBride and Bell, 2014). For environmental waters impacted by treated wastewater, the ideal pathogens considered for this human risk assessment are the viruses norovirus, enterovirus and adenovirus. Norovirus, adenovirus and enterovirus (McBride 2016a,b) have been used as representative viruses for several previous QMRAs in New Zealand (McBride 2011, 2012, 2016a,b), considering that they are significant contributors to water-borne infections. Hence, in this study, norovirus and enterovirus were used as reference QMRA pathogens for primary contact recreation (e.g. swimming) and shellfish consumption. Adenovirus Type 4 was used as reference QMRA pathogen for secondary contact recreation e.g. inhalation of aerosolised pathogens during water-skiing or during access to the river close to the outfall.

Norovirus infections cause acute gastroenteritis in humans. Symptoms, although self-limiting, include projectile vomiting, and watery non-bloody diarrhoea with abdominal cramps and nausea occurring typically within 10 to 50 hours after exposure. Infected persons shed large numbers of viral particles to the environment. Published literature have reported that in about two third (65%) of the surface water associated viral disease outbreaks, noroviruses have been identified as the cause of the illness (Sinclair et al. 2009). Norovirus outbreaks can occur throughout the year, but have been reported to occur more frequently during the colder winter seasons in temperate climates (Lofranco 2017; CDC 2014; Maunula, Miettinen, and Von Bonsdorff 2005; Ahmed, Lopman, and Levy 2013). A similar observation was made in the scoping and surrogate study on virus concentration at Mangere WWTP influent, New Zealand (Simpson et al.2003).

Enteroviruses are also transmissible via sewage contaminated waters (Lofranco 2017; Health Canada 2012). Although human enterovirus outbreaks can occur throughout the year depending on the strain, in temperate climates, enterovirus infections are most prevalent during summer months (Sedmak, Bina, and MacDonald 2003; Costan-Longares et al. 2008; PHAC 2015) unlike Noroviruses which seem to occur more frequently during the colder winter seasons in temperate climates (Lofranco 2017; CDC 2014; Maunula, Miettinen, and Von Bonsdorff 2005; Ahmed, Lopman, and Levy 2013). Typical concentrations of these reference viruses in untreated wastewater are presented in Table 4 (see Section 5.3) and are in line with values have been documented in several previous New Zealand QMRAs (e.g. McBride 2011, 2016a, b).

Adenoviruses are often detected in these same environments as noroviruses and enteroviruses (Choi and Jiang 2005; Sassoubre, Nelson, and Boehm 2012). However, compared to other viruses, it has been reported to have prolonged survival time and increased resistance to disinfection e.g. UV treatments (Albinana-Gimenez et al. 2009; Wyer et al. 2012; Kundu, McBride, and Wuertz 2013; Hewitt et al. 2013). This pathogenic virus has a low infectious dose and is thus of great importance in public health (Donzelli et al. 2015). Human adenoviruses (HAdVs) cause numerous symptomatic and asymptomatic infections affecting the respiratory tract (Carducci et al. 2016). Adenovirus Type 4 are one of the most commonly associated with acute respiratory for which dose responses have been formulated. Only a small proportion (less than 10%) of detectable adenovirus is as infectious as Adenovirus type 4 (Kundu et al. 2013).

2.3 Exposure Assessment

Exposure assessment involves identification of populations that could be affected by pathogens. The main individuals at risk of exposure to pathogens in the receiving environment of the Pōrangahau WWTP are those who engage in any sort of primary or secondary contact recreation or those who consume raw shellfish collected from any site potentially impacted by the discharge. In order to assess the potential level of exposure, the following were considered:

- proximity of the QMRA site to the discharge outlet and the fate of pathogens in the receiving environment (dilution, dispersion);
- possible exposure pathways that allow the pathogen to reach people and cause infection (through the air, through ingesting or inhalation of potentially polluted water, consuming potentially polluted shellfish etc.);
- range (minimum, maximum and median) of pathogen concentrations in treated effluent;
- the environmental fate of the microbial contaminants in the receiving environment: dilution of viral pathogens in the receiving marine environment;

- how much water a child[11] will ingest or inhale over a period of time during a particular recreational activity;
- how much raw shellfish harvested from the impact sites, an individual will consume at one sitting; and
- estimation of the amount, frequency, duration of time of exposure, and doses of an exposure.

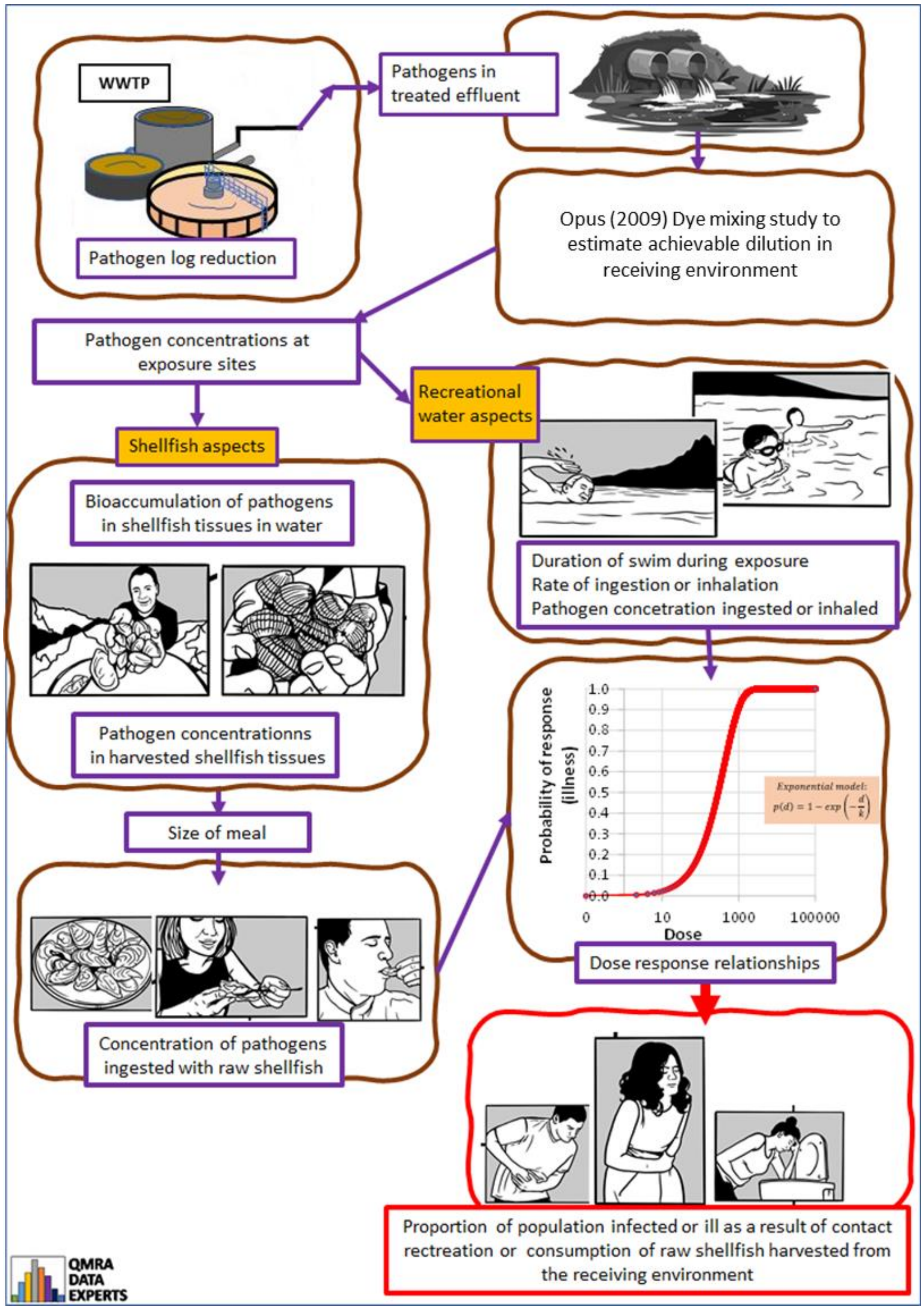

Figure 1 Procedural steps taken in the QMRA.

[11] A child is considered the worst-case risk because studies show that ingestion rates for children are twice as much as for adults (e.g. Dufour et al.2006) as reported in McBride (2017) QMRA for Bell Island WWTP outfall.

Table 1 Distributions and inputs for the QMRA

Parameter	**QMRA Statistics applied**	**Comments**
Influent concentration, Norovirus (genome copies per litre)	Minimum = 100 Median = 100,000 Maximum = 30,000,000	Hockey stick distribution, as previously described (McBride 2007, 2011; 2012; 2016 a,b). Norovirus harmonization factor of 18.5 was included, in line with McBride 2011 and 2017).
Influent concentration, Enterovirus (infectious units per litre)	Minimum = 500 Median = 4,000 Maximum = 50,000,000	
Influent concentration, Adenovirus (infectious units per litre)	Minimum = 2,000 Median = 5,000 Maximum = 30,000,000	
Duration of exposure event (e.g. swimming, kayaking, walking)	$\mu = 4.1, \sigma = 0.8$	Normal log distribution, exponential conversion to minutes, based on children swimming time documented in Table 2 of Schets et al (2011). Several previous QMRAs (McBride 2007, 2011; 2012; 2016 a,b, Dada 2018a; 2018b) have adopted Minimum = 0.1, Median = 0.25, Maximum = 2. However, this duration of swimming may not be conservative enough, when compared with estimates published in recent literature e.g., Schets et al (2011), hence the update to Schets et al's estimates in this QMRA report. Children typically spend about twice as much time in the water than adults (Dufour et al 2017) hence, the focus was on children.
Swimmer's water ingestion rate, mL per hour	Minimum = 0.6 Median =23.9 Maximum = 153.3	As applied in a recent NZ QMRA based on estimates for children swimming at specified points within the Wairoro-Waima-Hokianga system (Cressey 2021). Several previous QMRAs (McBride 2007, 2011; 2012; 2016 a,b, Dada 2018a; 2018b, relying on estimates published in Dufour et al, 2006) have applied PERT distribution spread between a Minimum, median and maximum of 20, 50 and 100ml/hr) for a child rate. More recently, Dufour et al (2017) reported that maximum volume of water ingested could be up to 279 mL. The estimates reported in Cressey (2021) could be over-conservative, with maximum volumes swallowed reaching 1,550mL. As it may be unrealistic for swimmers to ingest a litre of water during swimming, we therefore applied a truncation effect to modify the Cressey (2021) estimates. In this QMRA, total volume consumed = Swimmer's water ingestion rate, mL per hour * Duration of swimming event, truncated at 279 mL documented in Duffour et al. (2017)
Swimmer's water inhalation rate, mL per hour	Minimum = 0.4 Maximum = 4	Uniform distribution (double the rates reported in Rice et al 2012 for moderate activity). In this QMRA, total volume inhaled = Swimmer's water inhalation rate, mL per hour * Duration of exposure event.
Dose response parameters	Enterovirus (beta-binomial model, α = 1.3, β =75) Prob(illness/infection)= Uniform (0.24,0.57)	Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al. 2017, Soller et al. 2010a,b. Prob(illness/infection) is as documented in Moazeni et al (2017)
	Norovirus (beta-binomial model, α = 0.04, β =0.055) Prob(illness/infection)=0.6	Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al.2017, Soller et al. 2010 a,b
	Adenovirus Type 4 (simple binomial model, r = 0.4142). Only 10% of adenoviruses cause respiratory illnesses. Prob(illness/infection)=0.5	Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al. 2017, Soller et al. 2010 a,b, Kundu et al. 2013
Shellfish size per meal	α = 2.2046 β = 75.072 γ = -0.903	Loglogistic distribution between 5g and 800g, based on estimates of daily intake of consumers of raw shellfish (see McBride 2005, McBride 2007, 2011; 2012; 2016, Russel et al.1999, also applied in other QMRAs, e.g. Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al.2017, Soller et al. 2010 a,b)
Pathogen bioaccumulation factor (PBAF)	Mean = 49.9 Standard deviation = 20.93	Normal distributions around mean. Pathogen dose upon consumption of 100 grams of shellfish is a product of the PBAF and the number of pathogens in an equivalent volume of water (see Burkhardt & Calci 2000, McBride 2007, 2011; 2012; 2016, also applied in other QMRAs, e.g., Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al.2017, Soller et al. 2010 a,b).

2.3.1 Scenarios modelled

Three scenarios were considered in this QMRA study, as described in Table 2. Firstly we establish whether the current discharge situation, which will continue for the next six years, poses a threat to public health in relation to shellfish gathering and primary recreation. A second scenario predicted health risks, should the current treatment system be supplemented with a UV treatment system pending the commissioning of the proposed alternative land-based discharge. The third scenario considers the risks associated with the future land-based discharge option. The design of the land-treatment system predicts that the discharge will not reach the aquatic receiving environment. Notwithstanding this assumption, it was prudent to include a precautionary worst-case scenario where 5% of the land applied wastewater loads reach the Pōrangahau River.

Table 2: Scenarios modelled

Scenario	Description of scenario
Current_discharge (Pond_treatment_only)	Current condition, i.e. pond treatment at Pōrangahau WWTP and continued discharge into Pōrangahau River via a farm drain
Current_discharge_improved (Pond+UV treatment)	Improvement on current condition by supplementing existing pond treatment at Pōrangahau WWTP with UV treatment and continued discharge into Pōrangahau River
WWTP +UV treatment (assuming 5% "runoff")	Future discharge condition i.e. Pond+UV treated wastewater is not discharged into the Pōrangahau River but is instead applied to land. Notwithstanding, this scenarios models a precautionary worst-case situation in which up to 5% wastewater applied on discharge property ultimately reaches river by overland flow).

2.3.2 Dilution achieved in the receiving environment

During baseline discharge conditions, wastewater from Pōrangahau WWTP reaches the Pōrangahau river downstream of Pōrangahau township. While there are occasional low flows at this part of the river, in relation to dilution that would occur in the receiving environment, tidal interchange of water in this section of the river is more significant in the context of the wastewater discharge than the base river flow. A previous dye mixing study (Pōrangahau Township Oxidation Pond Discharge Mixing Study) was completed in 2009 by Opus to predict dilution of contaminants from the wastewater discharge plume in the receiving water. The key finding from the study was that there is large dilution of the wastewater, even at low flows, due to the small discharge from the WWTP.

In consultation with Beca, LEI and CHBDC, 4 key exposure sites (Sites 1-4) were identified in the Pōrangahau River and estuary receiving environment. These sites could be potentially impacted because of wastewater discharge (see Figure 2).

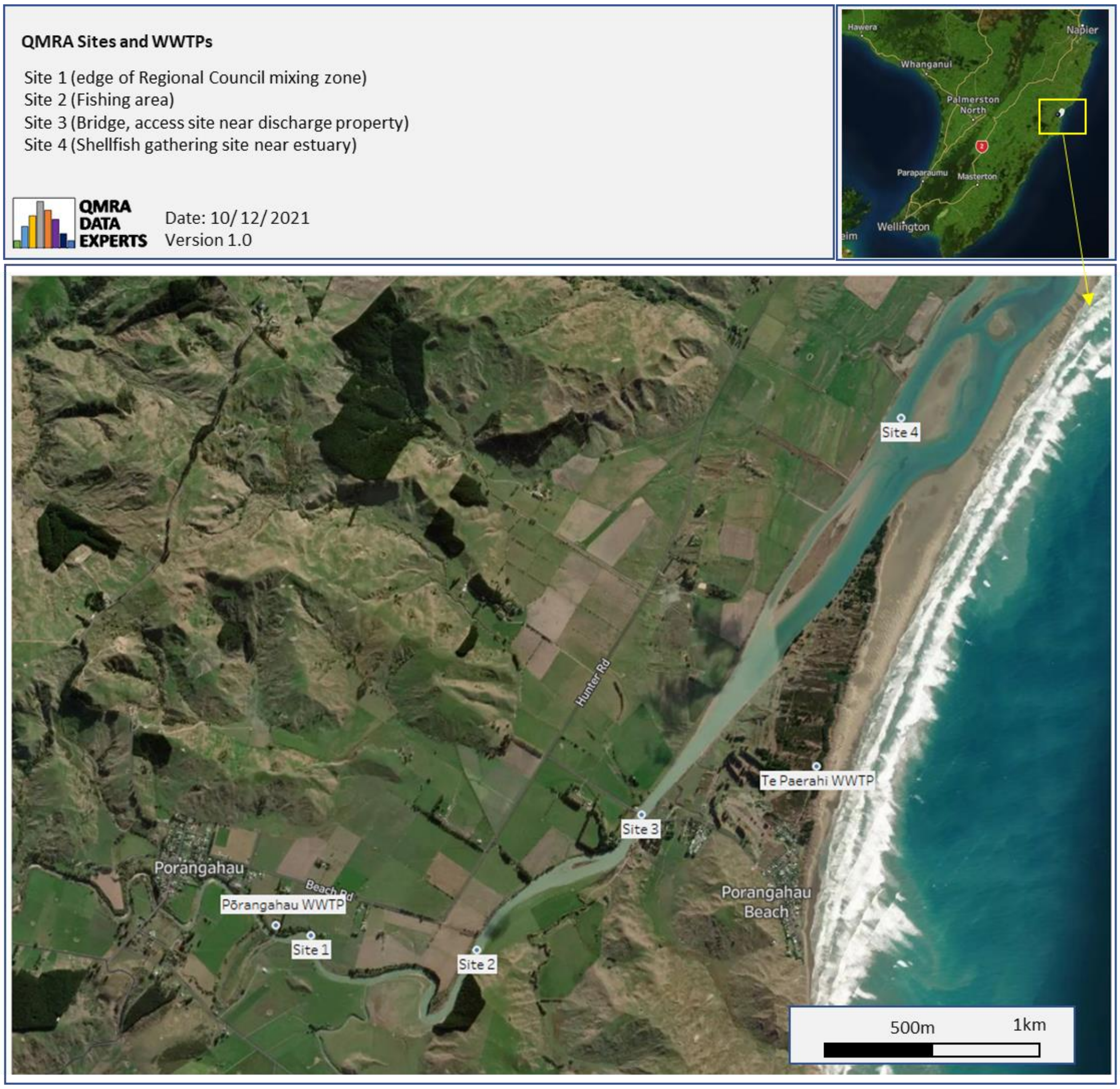

Figure 2. Location of the four selected exposure sites.

The mixing study results (Figure 3) show that:

- At the edge of the mixing zone (Site 1), approximately 200m downstream of the Pōrangahau WWTP discharge, dilution is at least 1000-fold and could be as high as 3,000-fold. This tidally influenced part of the river is 40m wide with a measured difference between high and low tide of approximately 0.5 m.
- Dilution further downstream is expected to be higher than observed at Site 1. A proportion-based approach (using the equations below) was used to statistically estimate dilution further downstream of Site 1.

- Using this approach, dilution at Sites 2,3,and 4 are expected to range from 2273 to 13,484-folds.

$$\mathit{Minimum\ dilution\ at\ Site\ y\ downstream\ of\ Site\ 1} = \left(1000 * \left(1 + \log\left(\frac{\mathit{distance\ of\ Site\ y\ downstream\ of\ discharge} * \mathit{width\ of\ receiving\ water\ at\ Site\ y}}{200 * 40}\right)\right)\right)$$

$$\mathit{Maximum\ dilution\ at\ Site\ y\ downstream\ of\ Site\ 1} = \left(3000 * \left(1 + \log\left(\frac{\mathit{distance\ of\ Site\ y\ downstream\ of\ discharge} * \mathit{width\ of\ receiving\ water\ at\ Site\ y}}{200 * 40}\right)\right)\right)$$

Where 200 is the distance (in meters) of Site 1 from the discharge and 20 is the width (in meters) of the receiving water at Site 1. 1,000 and 3000 are the minimum and maximum dilutions recorded at Site 1 in the dye dilution study. Sites 2, 3 and 4 are 60m, 90m and 130m wide as well as 3km, 4km and 7km from the current discharge site. It is assumed that "dilution only" influences the final concentration of viruses in the receiving environment following the discharge. Potential effects of other important variables such as micro-predation and solar UV inactivation are therefore not included.

Table 2: Dilution achievable in the receiving water (Pōrangahau River and Estuary)

Site	Min. dilution	Median dilution	Max. dilution	Source
Site 1 (approximately 200m downstream of the Pōrangahau WWTP)	1000	2000	3000	Mixing study
Site 2 (Fishing area, approximately 3km downstream of the current discharge site)	2273	4546	6819	Estimated from mixing study
Site 3 (Bridge with access site to river, approximately 4km downstream of the current discharge site)	3137	6274	9412	Estimated from mixing study
Site 4 (shellfish gathering site, approximately 7km downstream of the current discharge site)	4495	8989	13484	Estimated from mixing study

Using pert distributions, a 100000-fold Monte Carlo simulation was applied to generate time-series-like random dilutions spread between the minimum and maximum dilutions. Estimated 1st, 50th, 75th, 90th, 95th and 99th percentile of the achievable dilutions are presented in Figure 3.

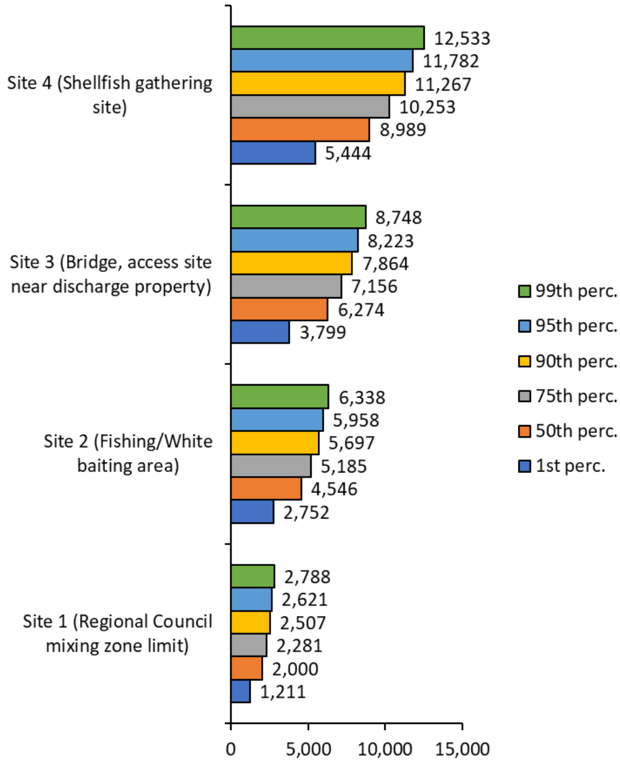

Figure 3 Dilutions achieved in the receiving environment following discharge of Pōrangahau WWTP wastewater.

2.3.3 Influent virus concentrations

In accordance with previous QMRA reports and international literature (e.g. Dada 2018a, b ,2019a, b, c, 2020, McBride 2011, 2012, 2013, 2016a,b), minimum, median and maximum virus concentrations documented for New Zealand WWTPs were bounded in the hockey-stick distribution in a way that the resulting data were strongly right-skewed with a hinge at the 95%ile. The RiskGeneral function in @RISK was then used to generate the random draws from the right-skewed distribution of virus concentrations. Therefore, this function allows presentation of the generally predominant lower virus concentrations (i.e. having higher probabilities) alongside the extreme concentrations (which may be rare, but substantial), which may occur during an on-going but undetected viral illness outbreak in the community. In this way, the QMRA aligns with the Resource Management Act, which defines an “effect” to include considerations for instances of rare (i.e. low probability of occurrence) but high potential impact. These “low probability events” (such as periods of infectious outbreaks in the community or WWTP system malfunction) coupled with elevated virus concentrations are effectively captured in the hockey-stick distribution.

To estimate final concentration of viral pathogens for each of the 4 exposure sites, the reciprocal dilution factors[12] estimated from the dye mixing study were multiplied by the hockey-stick[13] fitted concentrations of viruses in the sewage discharging from the Pōrangahau WWTP. The final virus concentrations in the water at each of the exposure sites on a random day were then subjected to varying log removals (depending on the treatment scenario considered) before they were incorporated into the QMRA. This method is consistent with the methods that have been used in several previous NZ QMRAs, for example Napier, Bell Island, Clarks Beach, Bell Island, Army Bay, Gisborne WWTPs (Dada 2018a, b ,2019a, b, c, 2020, McBride 2011, 2012, 2016a,b, Hudson 2019).

2.3.4 Virus reductions achieved at the Pōrangahau WWTP

Beca has advised on achievable log reductions in the current and future discharge scenarios, based on published literature. Current wastewater treatment at the Pōrangahau WWTP is based on a single oxidation pond that achieves a maximum of 2 log virus reductions (for enterovirus and norovirus). Given the proposed UV system proposed for the future discharge system, higher virus log reductions will be achieved (Figure 4).

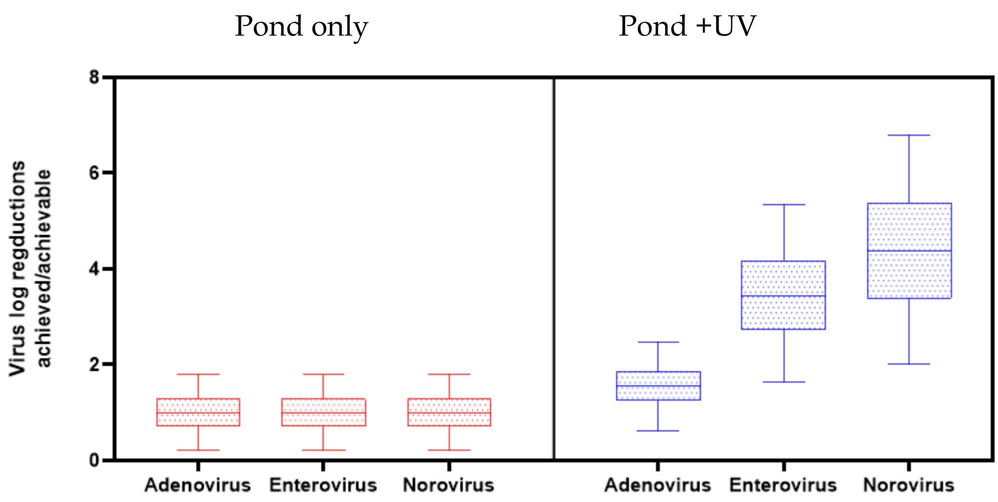

Figure 4 Pond only and Pond +UV log reductions achievable at the Pōrangahau WWTP

2.3.5 Predicting exposure doses

The dose of the pathogen that an individual encounters is an important component of the dose-response models used to predict the probability of infection or illness. In order to convert pathogen concentrations into doses, reference was made to the influent virus concentrations, and the ingestion rates for the water users (children, in

[12] Sampled from the entire reciprocal dilution range using a "riskcumul" function. This is a cumulative distribution which uses the parameters (minimum, maximum, range of values i.e. spread between the 10th and 99.9th percentile, and the cumulative probabilities of each value in range i.e. spread between 0.1 and 0.999). This is consistent with previous New Zealand QMRAs.
[13] To achieve a hockey-stick distribution of virus concentrations, minimum, median and maximum virus concentrations documented for New Zealand WWTPs are bounded in a way that the resulting data were strongly right-skewed with a hinge at the 95%ile. This is consistent with previous QMRA reports and international literature (e.g. Dada 2018a, b ,2019a, b, c, 2020, McBride 2011, 2012, 2013, 2016a,b).

the case of swimming or other primary contact recreation). Details of QMRA inputs of ingestion and inhalation rates are presented in Table 1.

The risks due to water ingestion rates during swimming, (Table 1) were based on previous studies that have applied biochemical procedures to trace a decomposition product of chlorine-stabilizing chloroisocyanurate, which passes through swimmers' bodies unmetabolized (Dufour et al. 2006, McBride 2016).

The dose of pathogens that individuals are potentially exposed to, following inhalation of aerosols in the vicinity of the receiving environment during secondary recreation is related to the inhalation rates. Previous QMRAs in New Zealand applied inhalation rates of 10-50ml per hour which are too conservative. For instance, if this rate were to be applied in an exposure event that last 2-3 hours, it invariably means that the individual engaging in the activity would have inhaled up to 150mL of water. In a study that assessed health risk associated with inhalation of potentially contaminated river water, the mean quantity of water inhaled by the nose during a swimming episode was 10 ml (Cabanes et al 2001). This corresponds to the amount prescribed for nasal irrigation (5 ml per nostril), which is representative of a prolonged swim with the head underwater. The limitation with this estimate is the lack of variability in the volume inhaled as this would vary with intensity of activity in the water. More recently, previous international studies report that with moderate intensity of activity, pool water inhalation appears to be approximately 0.2–2 mL/h (Rice et al 2012, USEPA 2009). To allow for extreme intensity of activity e.g. kayaking, we applied double this rate in our QMRA (i.e. 0.4-4 mL/h).

The risks due to consumption of raw harvested shellfish, were in line with estimates of daily intake of 98 consumers of mussels, oysters, scallops, pipi and tuatua in the 1997 National Nutrition Survey, as reported in previous New Zealand QMRAs (e.g. Dada 2018a,b, Stewart et al.2017, McBride 2005, 2016a,b).

It is important to note that previous QMRA reports (e.g. McBride 2016 a, b) have assessed risks due to ingestion of raw shellfish tissue using bivalve molluscs as the vector. This is because bivalve molluscs are very common and accessible in New Zealand waters, are very frequently consumed raw; and because they are known to 'bioaccumulate' pathogens, hence the additional multiplier effect called the pathogen bioaccumulative factor (PBAF, see Table 1) applied in our model (Bellou, Kokkinos, and Vantarakis 2013; Hanley 2015; Hassard et al. 2017)

2.3.6 Dose-response models

Dose-response models estimate the risk of a response (for example, infection or illness) given a known dose of a pathogen. They are mathematical functions, which describe the dose-response relationship for specific pathogens, transmission routes and hosts. Dose-response functions applied are stated in Table 1[14].

[14] Also plotted in Appendix 3

2.3.7 Risk characterization

Information from the previous steps was incorporated into **Monte Carlo simulations** to determine the likelihood of illness from exposure to pathogens. The Monte Carlo simulation is a randomization method that applies multiple random sampling from distributions assigned to key input variables in a model, in a way that incorporates the uncertainty profiles of each key input variable into the uncertainty profile of the output.

Typically, in a Monte Carlo model run, 100 individuals who do not have prior knowledge of existing contamination in the water are 'exposed' to potentially infectious water on a given day, and this exposure is repeated 1,000 times or days. Therefore, the total number of exposures is 100,000[15]. The result of the analysis is a full range of possible risks, including average and worst-case scenarios, associated with exposure to pathogens during the identified recreational activities or following consumption of raw shellfish. Monte Carlo simulations were undertaken using @Risk software (Palisade, NY). QMRA results are reported in terms of both infection and illness. It is noted however, that not all individuals who become infected eventually become ill. Although pathogen-dose response models in literature were determined based on infection endpoint, illness endpoint can be estimated simply using a uniform probability for illness as was done in several previous QMRAs (e.g. McBride 2011, 2017). Infection/illness ratios of 0.6 and 0.5 were applied for noroviruses (McBride 2016) while for enteroviruses, a uniform distribution (min=0.24, max= 0.57) was applied, consistent with published literature (Moazeni et al 2017).

The predicted risk is reported as the IIR (individual illness risk), calculated as the total number of infection cases divided by the total number of exposures, expressed as a percentage. The IIR is then compared with thresholds defined in the New Zealand "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*" (Table 3, MfE/MoH 2003, Table H1, page H25).

Consistent with the MfE/MoH guidelines, in the case of risk due to gastroenteric illnesses as a result of ingestion of polluted water while swimming or consumption of raw shellfish harvested from the impacted sites, the following **<u>thresholds</u>** were applied:

- high illness risk (>10% GI illness[16]);
- moderate illness risk (5-10% GI illness);
- low illness risk (1-5% GI illness);
- NOAEL (<1%); the 1% IIR threshold, also referred to as the "no observable adverse effects level" (NOAEL), is the widely-accepted threshold when assessing the effect of wastewater discharge on recreational health risk (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al.2017).

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[15] The mean infection case rate over the exposed 100 persons exposed is expressed in percentage, as IIR.

[16] Gastrointestinal illness

These risk categories are consistent with those defined in the MfE/MoH (2003) guidelines for marine waters containing:

(a) Less than 40 enterococci/ per 100 mL (NOAEL);
(b) 40 to ≤ 200 enterococci per 100 mL (1-5% GI risk),
(c) 201 to ≤ 500 enterococci per 100 mL (5-10% GI risk),
(d) > 500 enterococci per 100 mL (>10% GI risk),

In the case of acute febrile illness risks due to inhalation of pathogens in aerosols, near or at the impacted sites, comparatively lower thresholds apply:

- high illness risk (>3.9% AFRI illness);
- moderate illness risk (1.9-3.9% AFRI illness);
- low illness risk (0.3-<1.9% AFRI illness);
- NOAEL (<0.3%).

These risk thresholds have been applied severally in previous NZ QMRAs (Appendix 4) that assessed shellfish and recreation-related health risks in water receiving treated wastewater discharges.

Table 3 Estimated risk categories defined in the NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (pasted from MfE/MoH 2003)

Table H1: Guideline values for microbiological quality of marine recreational waters

95th percentile value of enterococci/100 mL (rounded values)	Basis of derivation	Estimated risk
≤ 40	This value is below the NOAEL in most epidemiological studies.	< 1% GI illness risk, < 0.3% AFRI risk. This relates to an excess illness of less than one incidence in every 100 exposures. The AFRI burden would be negligible.
41–200	The 200/100 mL value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or LOAEL for GI illness and AFRI.	1–5% GI illness risk, 0.3–< 1.9% AFRI illness risk. The upper 95th percentile value of 200 relates to an average probability of one case of gastroenteritis in 20 exposures. The AFRI illness rate at this water quality would be 19 per 1000 exposures, or approximately 1 in 50 exposures.
201–500	This level represents a substantial elevation in the probability of all adverse health outcomes for which dose–response data is available.	5–10% GI illness risk, 1.9–3.9% AFRI illness risk. This range of 95th percentiles represents a probability of 1 in 10 to 1 in 20 of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI in the range of 19–39 per 1000 exposures, or a range of approximately 1 in 50 to 1 in 25 exposures.
> 500	Above this level there may be a significant risk of high levels of minor illness transmission.	> 10% GI illness risk, > 3.9% AFRI illness risk. There is a greater than 10% chance of illness per single exposure. The AFRI illness rate at the 95th percentile point of 500 enterococci per 100 mL would be 39 per 1000 exposures, or approximately 1 in 25 exposures.

3. QMRA Results and Discussion

The average individual illness risk[17] (IIR) results of the QMRA analysis for individuals exposed to a reference virus pathogens under varying Pōrangahau WWTP discharge scenarios are presented in Table 4, Table 6, and Figure 5 to Figure 9. The values in the tables indicate the proportion (in percentage) of exposed individuals who are predicted to become ill.

Some other considerations are important with respect to predicted risks associated with the discharge. A first consideration is that the IIRs presented in this report do not apply to a specific virus log reduction *per se* but reflect randomly sampled achievable virus log reductions within the range that Beca have provided. A second consideration relates to the extreme conservative approach used in this study, which assumes that shellfish will be consumed raw. A third consideration relates to the very high influent virus concentrations applied in the model, which were mostly based on the outbreak-type situation reported in the Mangere scoping study (DRG, 2002). These elevated concentrations reflect the condition of the community at that time, and subsequent studies have not reported such elevated virus concentrations in New Zealand. For instance, based on findings from our on-going collaboration in a yearlong WWTP influent virus monitoring study (Viroflow Project), lower norovirus concentrations have been encountered. The inclusion of occasional very high influent virus concentrations that may occur during on-going but undetected viral illness outbreak in the community is highly conservative, notwithstanding. It is safer from a public health perspective to include these worst-case scenarios.

Although sunlight-based ultraviolet inactivation may occur in the receiving environment, which serves to reduce the concentrations of pathogens particularly in summer, a conservative assessment has been undertaken that assumes no microbial inactivation due to solar radiation in the receiving environment following discharge. Despite being an important factor affecting fate of pathogens in receiving waters (Noble et al 2004, Silverman 2013, Linden et al 2007; Jin & Flury 2002), the effectiveness of sunlight inactivation of waterborne viruses depends on complex and variable environmental factors (e.g. the intensity and spectrum of sunlight), characteristics of the water containing the virus particles (e.g. pH, DO, ionic strength, source and concentration of photosensitizers), and peculiarities of the virus particles (e.g. virus structures, genome type and prevalence of sites susceptible to photo-transformation; protein capsid composition and structure, see Anders 2006; Kohn et al. 2007; Love et al. 2010; Romero et al. 2011; Sinton et al. 1999). Despite uncertainties around the actual rates of UV inactivation that would take place in the receiving environment, it is certain that ultraviolet inactivation will occur, particularly in summer when primary contact recreation occurs. This highly conservative stance may mean that risks profiles reported in this report are over-estimated.

Another precautionary approach applied throughout the recreational health risk modelling to optimize public health protection was the reporting of children's recreational illness risk as opposed to the generally lower adults' risk based on the

[17] Averaged out for a group of 100 recreational users exposed on any random occasion, expressed as a percentage.

assumption that children typically spend about twice as much time in the water, and swallow about four times as much water than adults during swimming activities than adults (Dufour et al 2006, 2017).

Table 4 Enteric Illness health risk (%) for child receptors at primary contact recreation sites for two virus pathogens given different treatment/discharge scenario.

Reference pathogen	Scenario	Site 1	Site 2	Site 3	Site 4
Norovirus	Current_discharge (Pond_treatment_only)	1.642	1.126	0.946	0.76
Enterovirus	Current_discharge (Pond_treatment_only)	1.281	0.835	0.694	0.548
Norovirus	Current_discharge_improved (Pond+UV treatment)	0.05542	0.02594	0.01952	0.01458
Enterovirus	Current_discharge_improved (Pond+UV treatment)	0.02588	0.01118	0.00796	0.0062
Norovirus	WWTP + UV +UV treatment (assuming 5% “runoff”)	0.00576	0.00238	0.00184	0.00136
Enterovirus	WWTP +UV treatment (assuming 5% “runoff”)	0.00234	0.00102	0.00058	0.00054

Table 5 Acute respiratory illness health risk (%) for child receptors at secondary contact recreation sites for adenovirus given different treatment/discharge scenario.

Reference pathogen	Scenario	Site 1	Site 2	Site 3	Site 4
Adenovirus	Current_discharge (Pond_treatment_only)	0.383	0.184	0.138	0.097
Adenovirus	Current_discharge_improved (Pond+UV treatment)	0.131	0.058	0.044	0.030
Adenovirus	WWTP +UV treatment (assuming 5% “runoff”)	0.011	0.004	0.003	0.003

Table 6 Enteric illness health risk at shellfish harvest sites for two viral pathogens given different treatment/discharge scenarios.

Reference pathogen	Scenario	Site 4
Norovirus	Current_discharge (Pond_treatment_only)	5.677
Enterovirus	Current_discharge (Pond_treatment_only)	3.125
Norovirus	Current_discharge_improved (Pond+UV treatment)	0.472
Enterovirus	Current_discharge_improved (Pond+UV treatment)	0.28606
Norovirus	WWTP +UV treatment (assuming 5% “runoff”)	0.0851
Enterovirus	WWTP +UV treatment (assuming 5% “runoff”)	0.04182

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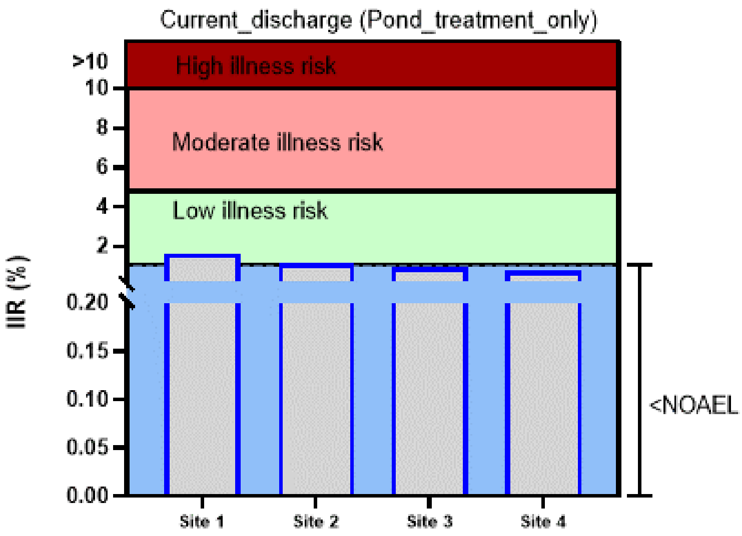
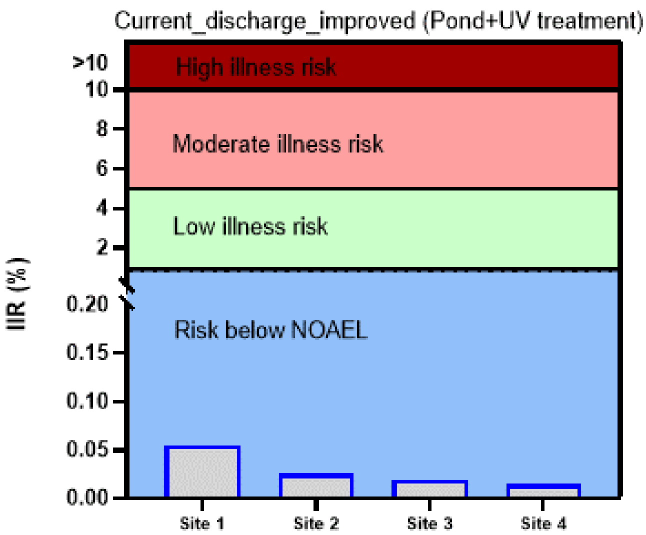




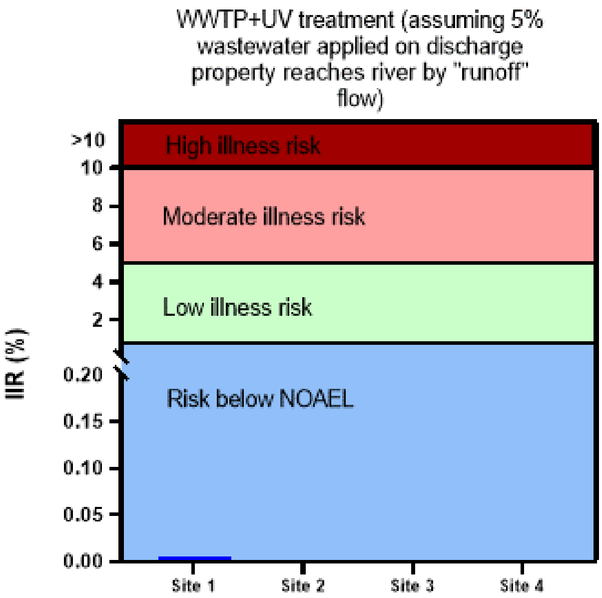
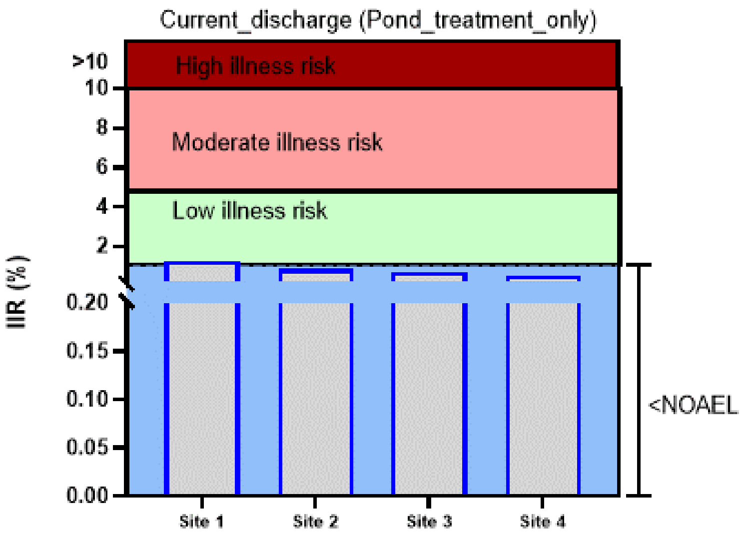
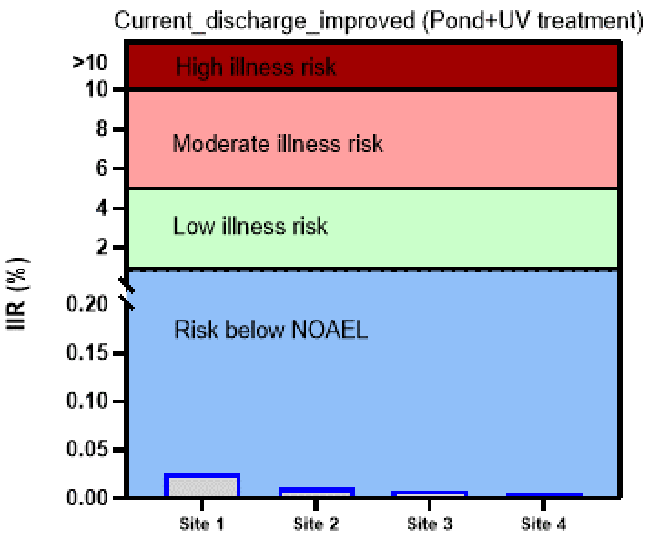


Figure 5 Child gastrointestinal illness risk (based on norovirus) associated with primary contact recreation at the various exposure sites. Virus log removals applied were a range of client-provided, achievable log reductions randomly sampled using 10,000-iterations of Monte Carlo simulation.





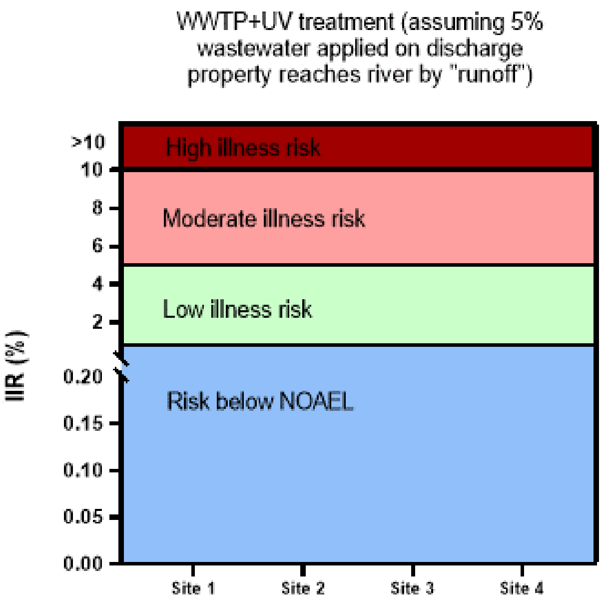


Figure 6 Child gastrointestinal illness risk (based on enterovirus) associated with primary contact recreation at the various exposure sites. Virus log removals applied were a range of client-provided, achievable log reductions randomly sampled using 10,000-iterations of Monte Carlo simulation.

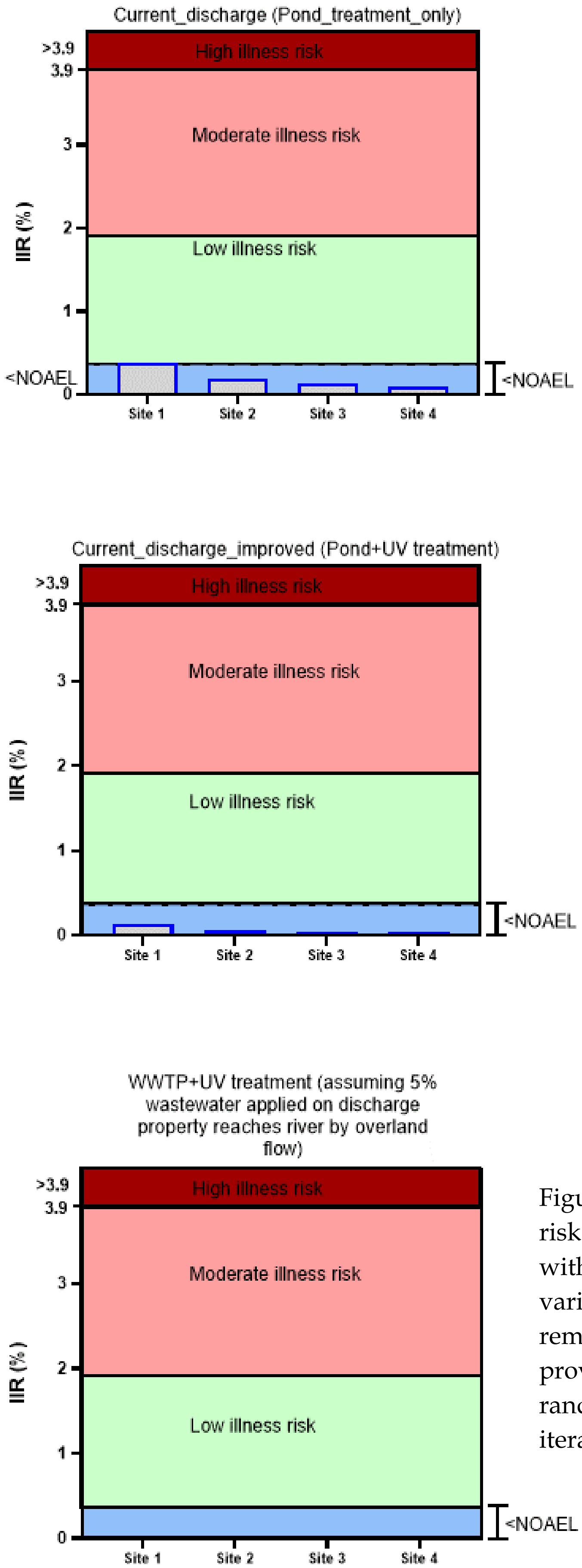


Figure 7 Child acute respiratory illness risk (based on adenovirus) associated with secondary contact recreation at the various exposure sites. Virus log removals applied were a range of client-provided, achievable log reductions randomly sampled using 10,000-iterations of Monte Carlo simulation.

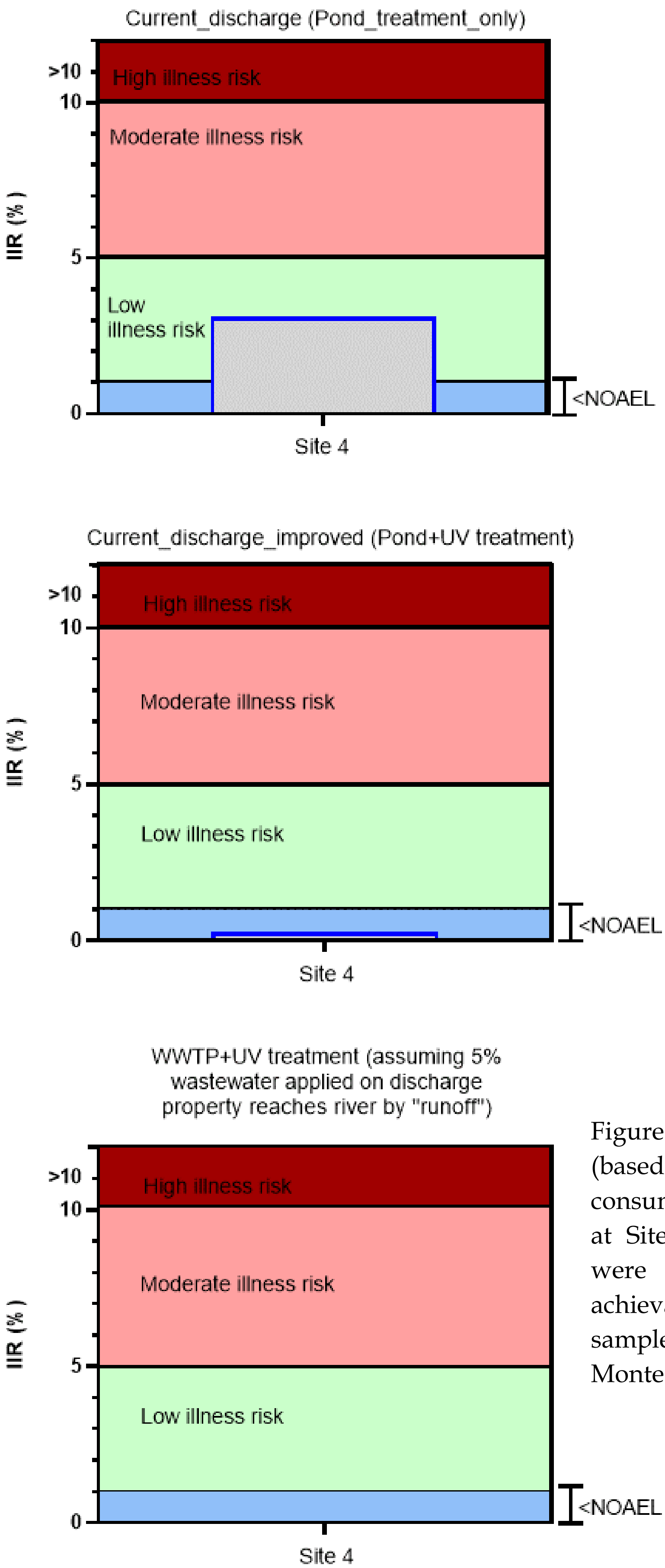
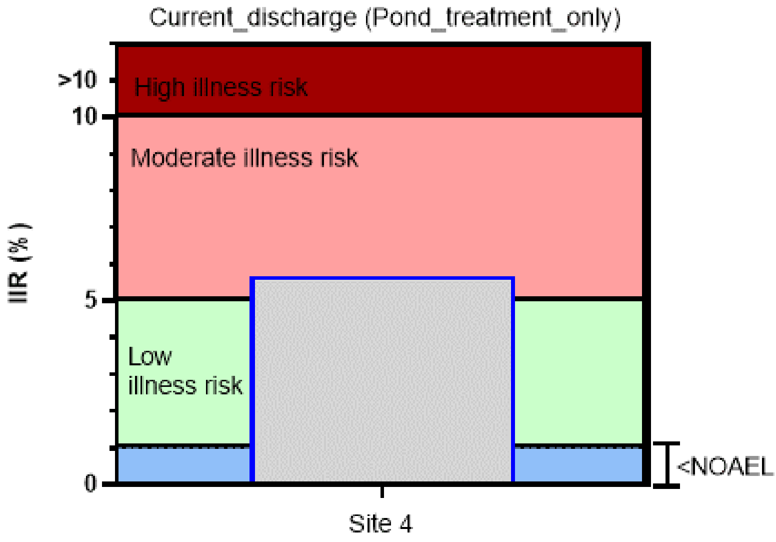
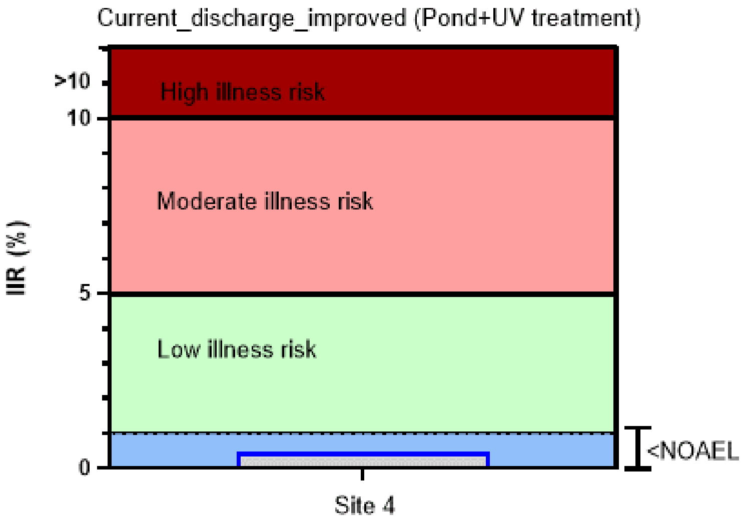


Figure 8 Gastrointestinal illness risk (based on enterovirus) associated with consumption of raw shellfish harvested at Site 4. Virus log removals applied were a range of client-provided, achievable log reductions randomly sampled using 10,000-iterations of Monte Carlo simulation.





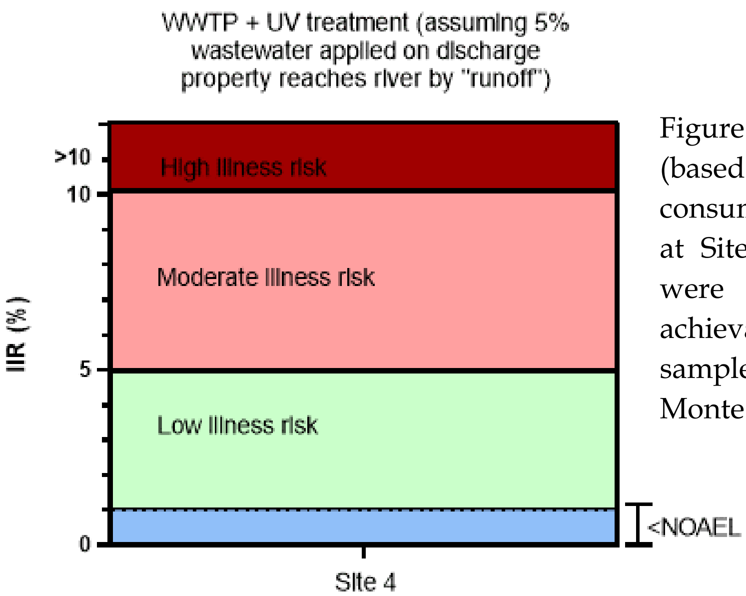


Figure 9 Gastrointestinal illness risk (based on norovirus) associated with consumption of raw shellfish harvested at Site 4. Virus log removals applied were a range of client-provided, achievable log reductions randomly sampled using 10,000-iterations of Monte Carlo simulation.

3.1.1 Risk associated with primary contact recreation (e.g., swimming)

During current treatment and discharge conditions, predicted individual illness risks associated with swimming were generally low, and ranged from 0.548% to 1.642% (Table 4). The results of QMRA analysis show that IIR profiles reduced with increasing distance downstream of the Pōrangahau discharge (Table 4), i.e. Site 1> Site 2> Site 3> Site 4. Compared to enterovirus, predicted IIRs were higher when norovirus was used as a representative pathogen, norovirus having generally higher illness risks attributable to the nature of its dose response function. Based on norovirus, predicted IIRs were 1.642% and 1.126%, respectively at Site 1 (200m downstream of the current discharge) and Site 2 (fishing area, approximately 3km downstream of the current discharge site). Although these predicted IIRs at Site 1 and Site 2 exceed the 1% IIR threshold for "no observable adverse effects level" (NOAEL), it is important to emphasize that Site 1 is very close to the discharge and is not accessible to the public. While Site 2 may be accessible to the public for fishing, it is not certain that it is used for swimming, other than occasional partial body immersion to collect fish. There is however public access at Site 3, i.e., the bridge approximately 4km downstream of the current discharge site. Predicted IIR (0.946%) at this site is already at the brink of exceeding the 1% NOAEL threshold.

As indicated in Beca (2021), antecedent reports indicate this stretch of river is dominated by tidal influences with generally low baseflow (Beca, 2021). Hence, an interpretation of individual illness risks predicted for the various discharge scenarios is predicated on the assumption that the receiving water is mostly marine. Consequently, it was logical to relate these predicted individual illness risks with thresholds for marine waters defined in the MfE/MoH Guidelines[18] (e.g., Hudson and McBride 2017). For example, the predicted IIRs at the sites in the current discharge scenario generally falls within the 1-5% gastrointestinal illness category. This could be related to Grade B waters (i.e., equivalent to 95th percentile enterococci concentrations falling within in a range from 41 to 200 enterococci/100 mL during weekly surveillance monitoring, with an average probability of illness of one case of gastroenteritis in 20 exposures). <u>These results indicate a low human health risk associated with swimming due to the discharge of the pond-treated Pōrangahau WWTP.</u>

However, as a potential option, if in the interim UV treatment is added to the current Pōrangahau WW flow discharged into river, much lower IIRs are predicted. For instance, with additional log reductions potentially achievable with an installed UV treatment system, predicted IIRs generally ranged from 0.062 to 0.055%, nearly 18 times lower than the <u>NOAEL</u>. Additionally, <u>the improved treatment will reduce swimming-related health risk below the NOAEL at all sites</u> (Table 4). In the context of the MfE/MoH Guidelines, the predicted IIRs at receiving water sites in the current discharge scenario fall within the <1% gastrointestinal illness category and hence could be related to Grade A waters (i.e. equivalent to 95th percentile enterococci

[18] The marine water guideline values have been derived from epidemiological studies. These epidemiological studies are rarely carried out for freshwater and has not been conducted for New Zealand.

concentrations not exceeding 40 enterococci/100 mL, with an average probability of illness of less than one in every 100 exposures).

The proposed future land treatment system is designed so that no overland flow occurs. Notwithstanding this design, using a precautionary worst case that assumes 5% of land applied UV-treated wastewater reaches Pōrangahau River (ignoring any land-based pathogen attenuation), it is predicted that health risks will fall below the NOAEL at all sites. Additionally, this scenario has the lowest IIR profiles of the three considered discharge options. In the context of the MfE/MoH Guidelines, the predicted IIRs at receiving water sites in the current discharge scenario fall within the <1% gastrointestinal illness category and hence could be related to Grade A waters.

3.1.2 Risk associated with secondary contact recreation (e.g., kayaking)

During current treatment and discharge conditions, individual illness risks associated with aerosol inhalation[19] was predicted to be low at Site 1 (IIR = 0.38%), equivalent to an average probability of 3.8 acute respiratory illness cases per 1000 exposures. The predicted IIR at Site 1 was marginally higher than the IIR threshold of 0.3% "no observable adverse effects level" threshold (Table 6). These results indicate a low acute febrile respiratory illness risk associated with exposure to aerosols at Site 1, 200 m downstream of the discharge. It is important to note that public access to this site is restricted, hence predicted low risks are conservative. At other sites further downstream (i.e. Sites 2, 3 and 4), predicted IIR are 0.184%, 0.138% and 0.097%, respectively. These predicted IIRs fall below the "no observable adverse effects level".

If in the interim, a UV treatment is added to the current Pōrangahau WW flow discharged into river, much lower IIRs are predicted. For instance, with additional log reductions potentially achievable with an installed UV treatment system, predicted IIR at Site 1 reduced to 0.130% at Site 1, equivalent to an average probability of 1.3 acute respiratory illness cases per 1000 exposures. At the remaining sites, predicted IIRs generally ranged from 0.030% at Site 4 to 0.058% at Site 2 (Table 6). Overall, the predicted IIRs at Sites 1, 2, 3 and 4, respectively, are 2.3x, 5.2x, 6.8x and 10x lower than the NOAEL. The improved treatment therefore reduced acute respiratory health risk below the NOAEL at all sites (Table 6).

The proposed future land treatment system is designed so that no overland flow occurs. Notwithstanding this design, using a precautionary worst case that assumes 5% of land applied UV-treated wastewater reaches Pōrangahau River (ignoring any land-based pathogen attenuation), it is predicted that acute respiratory health risk will fall below the NOAEL at all sites. Additionally, this scenario has the lowest IIR profiles of the three considered discharge options.

[19] During boating, kayaking and other activities that may expose individuals to inhalation of aerosols

3.1.3 Risk associated with consumption of raw shellfish

This QMRA adopted an approach that combined chances of an event occurring with hazards given an exposure route to predict consequential health risks. It was thus logical that to focus on exposure routes that does exist, that is, where shellfish gathering is conducted, hence, risks were only predicted for Site 4 in this study. Beca has advised that shellfish gathering occurs in this general area.

In addition to the conservative approach already applied for primary and secondary contact recreation illness risks assessment, a very conservative approach was also used in the shellfish risk assessment by assuming that shellfish harvested from the receiving environment would be consumed raw, contrary to MPI's warnings[20]. This conservative stance may mean that risks profiles reported in this report are over-estimated.

During current pond-based treatment and discharge conditions, predicted IIR at Site 4 was 5.677% and 3.125% respectively, based on norovirus and enterovirus pathogens (norovirus having generally higher illness risks attributable to the nature of its dose response function). The QMRA results therefore predict moderate health risks as a result of consuming raw shellfish harvested at Site 4.

However, if in the interim before the land-treatment system is fully developed, Pond+UV treatment is applied to the current WW flow discharged into Pōrangahau River, the improved treatment will reduce shellfish consumption-related health risk below the NOAEL at the shellfish gathering site (Site 4).

Future land discharge with improved treatment will reduce health risk even further, with predicted IIRs far below (~10 times lower than) the NOAEL at the shellfish gathering site (Site 4).

It is important to note that these health risks predictions are based on anticipated log reductions provided by Beca based on performance documented in previous literature. Uncertainties still surround actual virus log reductions that will be achieved once the installed UV plant is fully operational. This therefore necessitates an appropriate effluent and receiving environment monitoring plan to provide assurance that the plant is achieving the expected log reductions.

Consistent with several previous NZ QMRAs, this report adopted conservative bioaccumulation factors that assume shellfish concentrate viruses in their tissues. This report, however, does not include considerations for these viruses to settle in sediments. During dry weather, tidal and wind conditions may resuspend pathogens (from catchment flows and the WWTP overflow) that have been deposited or attached to particulate matter in bottom sand/sediment back into the water column (see Walters et al 2014). While microbial populations in sediment may be up to 2logs higher than in the overlying water column (Chavez-Diaz et al 2020, Dong et al 2019), we can't

[20] MPI encourages all to avoid eating raw shellfish. "Don't eat raw or undercooked mussels or other shellfish. Cook them before eating.". Available online at: https://www.mpi.govt.nz/news/media-releases/food-poisoning-associated-with-consumption-of-raw-mussels/

provide an accurate risk of exposure of pathogens from resuspension of sediment because of the complexities associated with sediment microbe analysis (e.g. lack of reliable pathogen sedimentation and resuspension rates, variable recoveries etc).

The complexity behind sediment microbes is not peculiar to Pōrangahau River, hence the reason why it is not included in this study and previous NZ QMRAs[21]. An ESR-led study was commissioned by Hawke's Bay Regional Council (HBRC) in 2019 to address problems in determining the significance of sediments as contributors to loadings of enteric indicators and pathogens in local waterways. The study raised questions as to "the origins of these elevated levels during dry weather, in particular, whether they came from sediment resuspension or other sources". One critical finding of the ESR study is stated below.

> *"Although no evidence of increased counts of indicator and pathogenic microbes in surface waters due to resuspension was found in the HBRC studies, there was nevertheless evidence of substantially elevated counts in the sediments" (Weaver & Sinton 2009).*

Regardless of whether or not sediment resuspension takes place, actual health risk associated with shellfish consumption will be less than is predicted in this report. This is particularly because these shellfish health risk predictions ignore solar inactivation and micro-predation that will occur in the receiving environment following discharge and prior to ingestion. For instance, the viruses could end up being preyed upon by other organisms such as choanozoans and picozoans. Viruses tend to be rich in phosphorus and nitrogen and could be good supplements to a carbon-rich diets in carbon-rich marine colloids (Brown et al 2020). Additionally, solar UV inactivation could also lead to reductions of virus concentrations in the receiving environment.

4. Conclusions

In terms of primary contact recreation (CR), results obtained from our highly conservative QMRA modelling show that the current pond treated discharge is associated with low health risks. However, if in the interim, Pond+UV treatment is were to be applied to the current WW flow discharged into Pōrangahau River over the next six years, the improved treatment would reduce swimming-related health risk below the NOAEL at all sites. The proposed future land treatment system is designed so no overland flow occurs. Notwithstanding this design assumption, we have assumed a precautionary worst case that assumes 5% of land applied UV-treated wastewater reaches Pōrangahau River (ignoring any land-based pathogen attenuation). Using this worst-case scenario, the predicted health risks falls below the NOAEL at all sites. Additionally, this scenario has the lowest IIR profiles of the three considered discharge options.

[21] Oldman and Dada (2020), Dada 2018a; 2018b; McBride 2007, 2011; 2012; 2016; Stewart et al. 2017,

Similarly, in terms of shellfish consumption (SF) , the current discharge is associated with moderate health risks at Site 4 where shellfish gathering occurs/potentially occurs. However, if in the interim, Pond+UV treatment were to be applied to the current WW flow discharged into Pōrangahau River, the improved treatment would reduce shellfish consumption-related health risk below the NOAEL at all sites. Future land discharge with improved treatment will reduce health risk below the NOAEL at this site.

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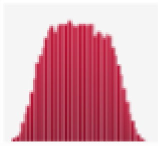
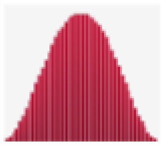
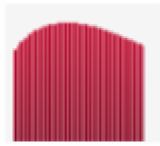
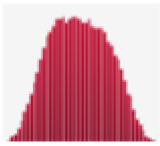
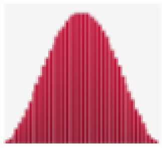
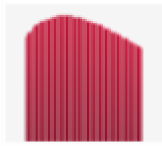
Appendix 1. Expected norovirus log reductions following pond-based and Pond+UV based wastewater treatment at Pōrangahau WWTP

Output	**Pond+UV log reduction**	**Pond_Log reduction**	**UV_Log reduction**
Scenarios	**Current_discharge_improved** **WWTP +UV treatment**	**Current_discharge (Pond_treatment_only)**	N/A
Function	Total WWTP Log reduction achieved = Pond+UV reduction + UV_Log reduction	Log reduction = RiskPert (0,1,2), truncated at min of 0 and max of 2. Parameters 0,1 and 2 are the minimum, most likely and maximum log reductions achievable at the WWTP	UV_Log reduction = RiskGamma (2,3). Truncated at min of 1.3 and max of 5.5. Parameters α and β are 2 and 3, respectively
Graphs of distribution			
Statistic			
Minimum	1.4443	0.0203	1.3000
Maximum	7.4509	1.9757	5.4999
Mean	4.3821	1.0000	3.3821
Mode	3.9562	1.0053	2.9171
Percentiles			
1%	2.0012	0.2112	1.3502
10%	2.7272	0.4932	1.7674
50%	4.3652	1.0000	3.3646
75%	5.3805	1.2811	4.3732
90%	6.0582	1.5067	5.0291
95%	6.3594	1.6215	5.2605
99%	6.8069	1.7887	5.4514

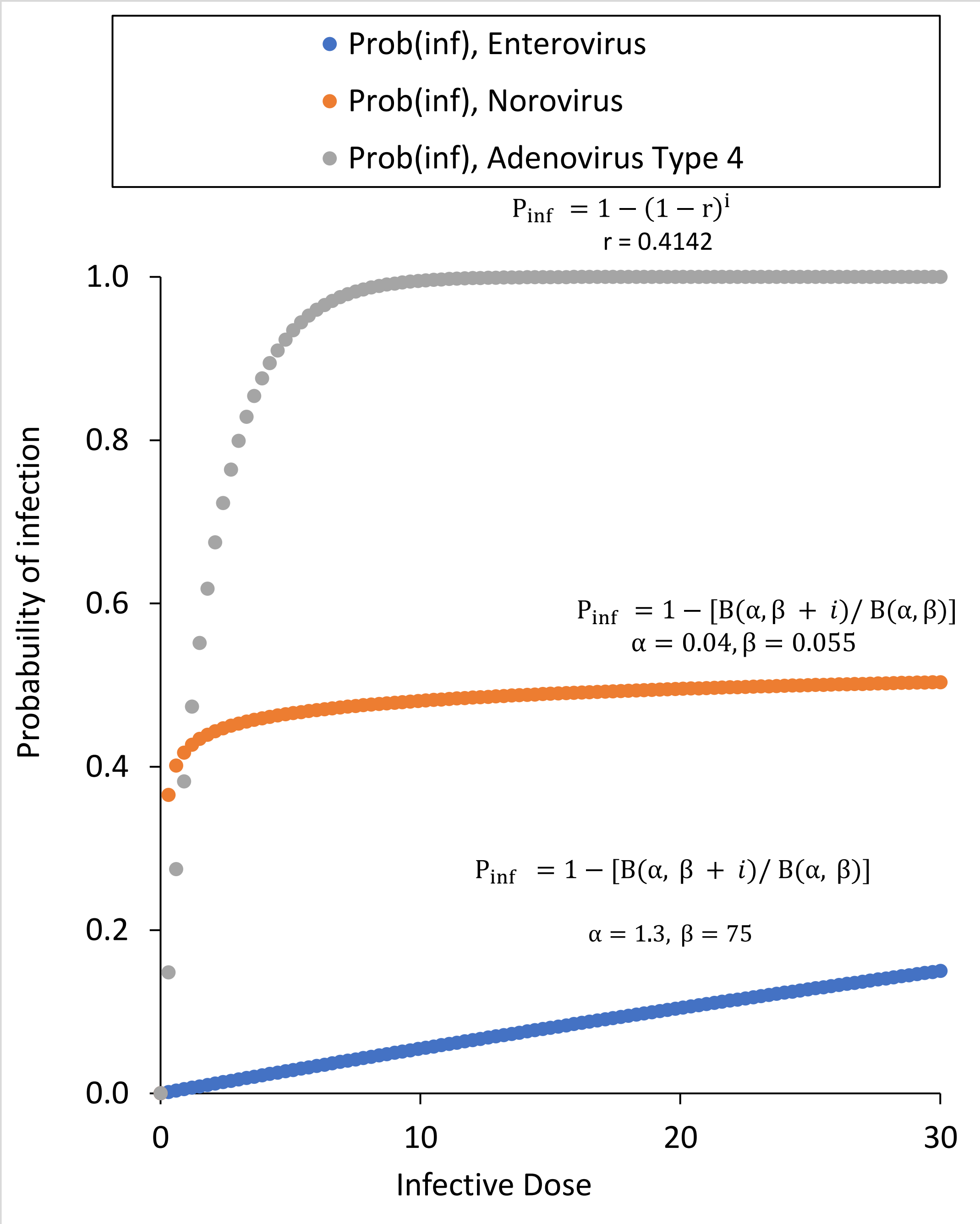
Readers should note that the final log reductions achieved are from randomly sampled log reductions from the Monte Carlo simulations and not merely calculated by numerically adding over rows of percentile log reductions presented in this table. 10,000 iterations of the random sampling was effected using @RISK.

Appendix 2. Expected enterovirus log reductions following pond-based and Pond+UV based wastewater treatment at Pōrangahau WWTP

Output	**Pond+UV log reduction**	**Pond_Log reduction**	**UV_Log reduction**
Scenarios	**Current_discharge_improved** **WWTP +UV treatment**	**Current_discharge (Pond_treatment_only)**	N/A
Function	Total WWTP Log reduction achieved = Pond+UV reduction + UV_Log reduction	Log reduction = RiskPert (0,1,2), truncated at min of 0 and max of 2. Parameters 0,1 and 2 are the minimum, most likely and maximum log reductions achievable at the WWTP	UV_Log reduction = RiskGamma (2,2). Truncated at min of 1 and max of 4. Parameters α and β are 2 each.
Graphs of distribution			
Statistic			
Minimum	1.1460	0.0230	1.0000
Maximum	5.8657	1.9746	4.0000
Mean	3.4529	1.0000	2.4529
Mode	3.1134	0.9840	1.9440
Percentiles			
1%	1.6177	0.2113	1.0329
10%	2.2406	0.4933	1.3115
50%	3.4347	1.0000	2.4262
75%	4.1715	1.2811	3.1566
90%	4.6995	1.5067	3.6436
95%	4.9582	1.6215	3.8180
99%	5.3448	1.7886	3.9629

Readers should note that the final log reductions achieved are from randomly sampled log reductions from the Monte Carlo simulations and not merely calculated by numerically adding over rows of percentile log reductions presented in this table. 10,000 iterations of the random sampling was effected using @RISK.

Appendix 3 Plots of individual dose response curve fitted for pathogenic viruses in this QMRA.



Appendix 4 Previous NZ QMRA studies and source of IIR thresholds applied

QMRA Study	**Risk assessed**	**Source of IIR thresholds applied**	**Authors**
Bell Island WWTP QMRA	Shellfish Recreation	Table H1, page H25NZ *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	McBride 2017
Wastewater overflow discharge consent - Queenstown Lakes District Council	Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	Hudson 2019
Water-Related Health Risks Analysis for the proposed Akaroa wastewater scheme Prepared for CH2M Beca Ltd	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	McBride 2014
Quantitative Microbial Risk Assessment for the discharge of treated wastewater: Proposed sub-regional wastewater treatment facility at Clarks Beach, South Manukau	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	McBride 2016
Quantitative Health Risk Assessment for Wet Weather Wastewater Discharges into City Rivers and Poverty Bay, Gisborne	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	Dada 2019
Health risks assessment of Raglan WWTP treatment and discharge options	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	Dada 2021
Quantitative Microbial Risk Assessment – Recent Advances in New Zealand and their Application to Moa Point WWTP Bypass Discharges	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	Crawford, McBride and Bell (2014)

A quantitative microbial risk assessment for Napier's City Ocean outfall wastewater discharge	Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	McBride 2011
The aberrational discharge of sewage from Nelson Sewerage Business Unit (NSRBU) Pump Stations (Technical evidence for Commissioners)	Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	Hudson 2017
Human health risk assessment: Raglan WWTP	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	Hudson 2019
Predictions of Human Health Effects Associated with Wet Weather Flows in Whangarei Effects on primary and secondary water contact, and consumers of raw shellfish	Shellfish Recreation	Table H1, page H25, *NZ Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*	McBride 2011