BEFORE NORTHLAND REGIONAL COUNCIL

UNDER	the Resource Management Act 1991
A N D	
IN THE MATTER	of applications to renew the resource consents associated with the operation of the wastewater treatment plants at Opononi and Kohukohu
BETWEEN	**FAR NORTH DISTRICT COUNCIL**
	Applicant
	NORTHLAND REGIONAL COUNCIL
	Consent Authority

STATEMENT OF EVIDENCE OF DR CHRISTOPHER AYOKUNLE DADA – QUANTITATIVE MICROBIAL RISK ASSESSMENT

3 May 2023

Counsel instructed:
Bronwyn Carruthers KC
Shortland Chambers
PO Box 4338
AUCKLAND 1140
bcarruthers@shortlandchambers.co.nz

INTRODUCTION

Qualifications and experience

1. My full name is Dr Christopher (Chris) Ayokunle Dada. I am an Environmental Health Microbiologist at QMRA Data Experts, a position I have held since June 2020.

2. Prior to this I was a Water Quality Scientist at Streamlined Environmental Ltd for 3 years and a Research Officer at the University of Waikato for 2 years. I also worked as a Research Fellow at the Institute of Ecology and Environmental Studies at Obafemi Awolowo University for a period of 4 years.

3. I hold the following relevant qualifications:

   (a) Bachelor of Science (First Class) in Microbiology from the University of Ado-Ekiti (2004);

   (b) Master of Science (Hons) in Water Science, Policy and Management from Oxford University (2007);

   (c) PhD in Water Microbiology from the National University of Malaysia (UKM) (2014); and

   (d) Postgraduate Certificate (Data Analytics), Massey University, New Zealand (2019).

4. I am an active researcher with a focus on projects that predict the effect of management decisions on water quality. This includes specialist expertise in microbiology, quantitative microbial risk assessment (**QMRA**) and predictive modelling. I have written 25 technical reports on microbial risk assessment in relation to New Zealand waterways. I have also published 18 peer-reviewed articles in international journals on public health aspects of faecal pollution in water. Most recently, I published in the Science of the Total Environment journal on

   (a) QMRA of occupational exposure to SARS-CoV-2 in wastewater treatment plants (2021) and,

   (b) Integrating life cycle assessment with quantitative microbial risk assessment for a holistic evaluation of sewage treatment plant (2023).

Involvement in Applications

5. Far North District Council (**FNDC**) engaged Streamlined Environmental Limited in 2020 to assist with the reconsenting of the wastewater treatment plants (**WWTP**) at Opononi and Kohukohu.

6. I undertook health risk assessments and produced a report for FNDC titled "A Quantitative Microbial Risk Assessment of the Opononi WWTP discharge and receiving environment" (**First Report**). Consistent with other NZ QMRAs, the focus was on viral gastrointestinal illness and acute respiratory illness risks (abbreviated as GI and AFRI illness risks, respectively).

7. I also undertook another semi-quantitative health risk assessment and produced a second report for FNDC titled "Semi-quantitative microbial human health risk assessment of Kohukohu WWTP discharge in the Hokianga Harbour" (**Second Report**). Consistent with previous NZ effects assessment studies, this study also addressed the enteric illness risks related to contact recreation and consumption of harvested shellfish, in relation to existing faecal indicator bacteria standards.

Code of Conduct

8. My qualifications as an expert are set out above. I confirm that I have read the Expert Witness Code of Conduct set out in the Environment Court's Practice Note 2022. I have complied with the Code of Conduct in preparing this evidence. Except where I state that I am relying on the evidence of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed in this evidence.

SCOPE OF MY EVIDENCE

9. My evidence addresses the following aspects of the application:

   (a) Quantitative Microbial Risk Assessment;

   (b) Response to issues raised in submissions;

   (c) Proposed consent conditions including monitoring plans;

   (d) Summary and conclusion.

QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA)

10. QMRA is a tool for estimating human health risks from exposure to pathogens via various environmental sources, e.g. water. As documented in literature, QMRA is typically described as a sequence of four steps listed below:

    (a) Hazard identification;

    (b) Exposure assessment;

    (c) Dose-response assessment;

    (d) Risk characterisation;

11. I explain each of these matters below.

First Report

Hazard Identification

12. Hazard identification involves a determination of pathogens and human health outcomes of concern. For environmental waters impacted by treated wastewater discharge into the Hokianga Harobur, the ideal reference pathogens considered for human risk assessment are the viruses: norovirus, enterovirus and adenovirus (McBride 2016a,b). These viruses have been used as representative viruses for previous studies in New Zealand (Dada 2018a; 2018b; Dada 2019; McBride 2007, 2011, 2012, 2016; Hudson 2019). While norovirus and enterovirus are significant contributors to gastroenteric illnesses[1], adenovirus (Type 4) can cause respiratory illnesses via inhalation of aerosols from contaminated water during swimming, water-skiing or people accessing the shore close to the outfall being subject to wave/wind driven spray. Hence, in the First Report, norovirus and enterovirus were used as reference QMRA pathogens for primary contact recreation and shellfish consumption. For secondary contact recreation, which includes activities such as shoreline walking, jogging, paddling, wading, boating and fishing, in which there may be some direct contact but the chance of swallowing water is unlikely, only adenovirus (Type 4) was used as reference pathogen for assessing risks associated with inhalation of potentially

[11] Gastroenteritis, also known as infectious diarrhea and gastro, is an inflammation of the gastrointestinal tract including the stomach and intestine. They typically present with symptoms such as diarrhea, vomiting, abdominal pain, fever and dehydration.

polluted water (e.g. from wind or wave-induced spray) containing aerosolised pathogens. The health outcome considered in the QMRA is illness.

Exposure Assessment

13. Exposure assessment involves a determination of the pathways of exposure and measuring or modeling the pathogen exposure doses during defined exposure events. The main individuals at risk of exposure to pathogens in the receiving environment of the Opononi WWTP are those that engage in any sort of contact recreation or those who consume raw shellfish collected from any site potentially impacted by the discharge.

14. The main considerations in the exposure assessment stage are listed in points (a) to (g) below:

    (a) The proximity of the exposure site to discharge outlet: FNDC identified 8 exposure sites in the Hokianga Harbour where recreation or shellfish gathering is likely to take place.

    (b) Exposure pathways are those that allow the pathogen to reach people and cause infection. Based on the information provided by FNDC, the QMRA report assumed that exposure pathways are mainly through the air during secondary contact recreation e.g. kayaking, shoreline walking or jogging; through ingesting contaminated water during primary contact recreation; and through consumption of raw shellfish.

    (c) There are no available data on the influent and effluent virus concentrations in the Opononi WWTP discharge. Notwithstanding, a range of influent virus concentrations have already been reported in long-term studies in New Zealand, and these have been used as representative influent virus concentrations in previous New Zealand QMRAs (e.g. Dada 2018a; 2018b; McBride 2016a,b). Consistent with previous NZ QMRAs, influent virus concentrations (minimum, maximum and median) applied in this QMRA were therefore based on these previous documented ranges (see Table 3).

    (d) Environmental fate of microbial contaminants in the receiving environment: A complex mix of processes determine the environmental fate of microbial contaminants, including dilution, pathogen inactivation by solar-radiation, die-off by predation, bioaccumulation, growth etc. Given the complexities in

estimating these parameters, the QMRA focused only on dilution and bioaccumulation. Dilution modelling was undertaken by MetOcean Solutions[2] and provided to me; and dilution factors for different sites across the Hokianga Harbour were used to conduct the QMRA. This approach is consistent with previous QMRAs undertaken in New Zealand.[3]

(e) How much water an individual will ingest over a period of time during a particular recreational activity: Child[4] water ingestion and aerosol inhalation rates applied in the QMRA report were consistent with previous QMRAs undertaken in New Zealand.

(f) Amount, frequency, length of time of exposure: Values for these parameters applied in the QMRA (see Table 3 of QMRA report) were consistent with previous QMRAs undertaken in New Zealand[5].

(g) Doses for an exposure: pathogen doses in each exposure were calculated from a combination of the preceding parameters.

Dose Response Assessment

15. Dose-response assessment involved the use of dose-response functions that have already been established from clinical test results from subsets of volunteers challenged with laboratory-prepared aliquots of pathogen suspensions at varying serial dilutions of known mean doses of pathogens (e.g. Haas et al 1999).

Risk Characterization

16. During the risk characterization stage, the calculated exposure doses and the established dose-response function for each pathogen considered, were used to calculate the likelihood of the health outcome. Risk characterization was conducted using Monte Carlo simulations, which model a variety of scenarios and help to account for variability and uncertainty in estimated health risks. Predicted risks are expressed

[2] Provided as Appendix J to the Application
[3] (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al 2017)
[4] A child is considered to be 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
[5] (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al 2017, Hudson 2019)

as individual illness risk (**IIR**) and classified into four groups in relation to the New Zealand recreational water quality guidelines (MfE/MoH 2003)[6].

17. In the case of risk due to enteric illnesses as a result of ingestion of water affected by treated wastewater discharge, while swimming or via the consumption of raw shellfish, predicted IIRs for each site are classified[7] into:

    (a) No observable adverse effects level (**NOAEL**, IIR <1%). This 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). When IIR is less than 1%, there is a probability of less than one case of enteric illness in every 100 exposures.

    (b) Low illness risk (IIR: 1-5% GI illness); that is, a maximum of 5 cases of illness in 100 exposures;

    (c) Moderate illness risk (IIR: 5-10% GI illness). An IIR above 5% presents an even greater chance of illness (1 in 20 to 1 in 10 cases of gastroenteritis for a single exposure);

    (d) High illness risk (IIR >10% GI illness); that is, a greater than 10% chance of illness per single exposure

18. In the case of acute febrile respiratory illness (**AFRI[8]**) risk due to inhalation of contaminated water, comparatively lower thresholds were applied (again, consistent with previous QMRAs):

    (a) NOAEL (IIR <0.3%). When IIR is less than 0.3%, AFRI is negligible, with a probability of less than three cases of acute febrile respiratory illness infection in every 1000 exposures.

    (b) Low illness risk (IIR: 0.3 - <1.9% AFRI illness). This means a probability of more than 3 but fewer than 19 AFRI cases per 1000 exposures;

[6] Table H1 the New Zealand recreational water quality guidelines (MfE/MoH 2003)
[7] Consistent with previous QMRAs
[8] Puro et al (2008) defined Febrile Respiratory Illness (FRI) is defined as a new or worsening episode of either cough or shortness of breath, presenting with fever (temperature 38 degrees C or higher) or chills in the previous 24 hours. The word “acute”, used as a reference to time, indicates that the symptoms appear suddenly and worsen rapidly but the condition is present for less than a month.

(c) Moderate illness risk (IIR: 1.9-3.9% AFRI illness). This means a probability of between 19 and 39 AFRI cases per 1000 exposures;

(d) High illness risk (IIR >3.9% AFRI illness). This means a probability of more than 39 AFRI cases per 1000 exposures;

19. The ideal health outcome, therefore, is that predicted illness risks fall below the acceptable 1% and 0.3% NOAEL thresholds for GI and AFRI illness risks, respectively.

20. A key objective of the QMRA was to present a comparative analysis. That is, I assessed health risks associated with treated discharge water following different levels of treatment (i.e. after 1-log, 2-log, 3-log and 4-log virus reduction) and following dilution in the receiving environment. I also determined the virus log reductions assumed to be achieved at the Opononi WWTP, as informed by previously published values for similar treatment systems. I then assessed whether this level of treatment is associated with any form of health risks based on our QMRA results for that level of treatment.

21. Two scenarios (*la nina* and *el nino*) that reflect possible climatic conditions were investigated in the QMRA.

22. A precautionary approach adopted was that all four WWTPs discharging into the harbour were simultaneously "turned on", such that the effect modelled at exposure sites in this QMRA for Opononi WWTP also captured additional effects from WWTPs upstream of the Opononi WWTP. This precautionary and conservative approach applied in the First Report, therefore, captures the cumulative effect of all WWTPs in the Hokianga harbour. Other precautionary and conservative approaches in the QMRA was achieved by accounting for extremely high influent virus concentrations that occur during on-going but undetected viral illness outbreaks in the community; applying a bioaccumulation factor to shellfish; and including a dilution-only scenario that does not include solar ultraviolet-based inactivation of viruses in the receiving environment.

23. In published literature, a 2log virus removal is the most predominantly reported level of reduction in virus concentrations in constructed wetland treatment systems

24. QMRA modelling results show that wastewater treatment that reduces virus concentrations in the WWTP discharge by 2-log (i.e. 100-fold) reduction will reduce health risks associated with the discharge (in relation to inhalation, ingestion during swimming and consumption of shellfish harvested) at all exposure sites, to levels below the NOAEL.

25. In line with the QMRA results, if the wetland treatment system is achieving a 2log virus removal, as commonly indicated by available literature, the level of treatment currently applied at the Opononi WWTP is sufficient to reduce illness risks associated with recreation or consumption of harvested raw shellfish below the "no observable adverse effect level" (NOAEL).

Second Report: Semi-Quantitative Microbial Risk Assessment

26. In the Second Report, I also undertook health risk assessments and produced a report titled "Semi-quantitative microbial human health risk assessment of Kohukohu WWTP discharge in the Hokianga Harbour". Consistent with previous NZ effects assessment studies, this study also addressed the enteric illness risks related to contact recreation and consumption of harvested shellfish.

27. In summary, the Second Report used an approach that applies faecal indicator bacteria (**FIB**) - namely enterococci for contact recreation, Escherichia coli (*E. coli*) in shellfish tissues, and faecal coliforms (**FC**) for shellfish-gathering waters - as "conservative" proxies of pathogens relevant to public human health risks.

28. Analysis of long-term monitoring data (2010-2019) shows that the Kohukohu WWTP discharge water FC concentrations ranged from 27 to 1.14×10^5 CFU/100mL[9] (Table 3), with a 95th percentile concentration of 2.44×10^4 CFU/100mL (Table 3). At least 50% of the time, monthly FC concentrations of the wastewater discharge were below 900 CFU/100mL (Table 3).

29. Aside from results presented in existing reports above, I also assessed historical data routinely collected by the NRC. Available water quality data for the CR3-SF3 site (i.e. Omapere at Old Wharf Road, downstream of the Opononi WWTP discharge) and Hokianga Harbour Opononi LAWA (upstream of the Opononi WWTP discharge) sites indicates that only low health risk exists at these sites if used for recreational bathing. For instance, the 5-year 95th percentile enterococci concentration for Omapere at Old Wharf Road and Hokianga Harbour Opononi are 52 enterococci/100 mL and 70 enterococci/100 mL, respectively . These concentrations are marginally above the threshold for sites classified as A in terms of the Microbiological Assessment Category (MAC) guidelines (Table 4), hence are classified as B. While there are no data on a recent Sanitary Inspection Category (SIC) for these sites, other potential contaminant sources (such as rural streams with animal faecal material, urban runoff draining

[9] Colony Forming Units per 100mL

catchments etc.) may lead to reduced water quality during storm events. This was reflected in the enterococci data routinely collected by NRC at CR3-SF3 site. For instance, enterococci concentrations at CR3-SF3 site generally did not exceed the acceptable single sample threshold of 140 enterococci/100 mL (Green mode, see upper image in Figure 8), except in one instance on the 3rd of December 2018 when a lot of storm water was released onto the beach (observed concentration on storm event day = 680 enterococci/100 mL).

30. Using dilution factors generated by MetOcean's three-dimensional hydrodynamic model, the impact of the Kohukohu treated wastewater discharge at 12 key recreational water contact and shellfish harvesting sites was assessed.

31. A key focus of the Second Report was on the resulting elevation of FIB in the receiving environment following WWTP discharge, during scenarios of not including and including environmental background concentrations.

Enteric Illness Risks Associated with Swimming

32. In terms of recreational health risk, results from this study show that enterococci in the current Kohukohu WWTP discharge with a worst-case (95th percentile) concentration of 24,400 CFU/100mL does not negatively impact recreational water quality. Based on dilutions achievable at the Hokianga Harbour, increases in faecal coliform in the receiving water even during the worst-case scenario is +1 CFU/100mL. Additionally, enterococci concentrations at all the 12 upstream and downstream sites considered in this study did not exceed the 140 CFU/100mL limit specified for "Acceptable/Green (surveillance) Mode" in the MfE/MoH (2003) policy document.

Enteric Illness Risk Associated with Shellfish consumption

33. The current quality of shellfish at the Hokianga sites does not meet the New Zealand Food Safety Authority (**NZFSA**) 2006 guidelines. For instance, during a short-term shellfish tissue quality monitoring study conducted as part of the Northland region's coastal monitoring exercise in the Hokianga Harbour, approximately 23-30% of individual samples exceeded the NZFSA guideline value of 700 *E. coli* per 100g.

34. However, based on dilutions achieved at the Hokianga Harbour after the discharge, predicted increases in faecal coliform in the receiving water during the worst-case scenario of treated wastewater discharge is only + 1 CFU/100mL. Given this negligible

change in water quality, the discharge is not expected to noticeably affect shellfish quality.

35. It is however important to emphasize that shellfish filter feed, hence, they can take up pathogens directly from the water column and accumulate this over time such that the accumulated pathogens can be present within the shellfish at levels high enough to elevate health risks once ingested (Grodzki et al 2014). In numerical terms, bioaccumulation may range from a factor of 1 to as high as 100 (average of 49.9, McBride 2016, Bellou et al., 2013; Hanley, 2015; Hassard et al., 2017). The actual level of bioaccumulation will depend on many factors including, the species being considered, their differing body sizes, tissue physiological composition, filtration activity etc (Grodzki et al 2014). Nonetheless, on average, an increase of +1 CFU/100mL of faecal coliforms in the water column may translate into higher concentrations of as much as 100 CFU/100mL in the shellfish tissues.

36. From analysis of these shellfish concentrations, it is not possible to ascertain what proportion of the elevated shellfish tissue *E. coli* concentrations are due to the discharges from Kohukohu WWTP. Other sources may also provide elevated *E. coli* concentrations, including re-suspension of bacteria-rich sediment during rough weather conditions, contributions from animals e.g. seabirds, livestock effluent, sewage overflows, and faulty or poorly maintained septic tank systems in the catchment.

37. I therefore recommended that a faecal source tracking study be commissioned to determine the cause of elevated shellfish tissue *E. coli* concentrations in the Hokianga Harbour. This approach was successfully adopted in the Northland Region following the observation of elevated *E. coli* concentrations in shellfish harvested from the Whangaroa Harbour. The Whangaroa harbour faecal tracking study results indicated that the sources of contamination were generally ruminant (herbivore) and wildfowl (Reed, 2011). It is not relevant in this instance to apply results from the Whangaroa Harbour to the conditions in the Hokianga Harbour, as land use may differ significantly in their contributory catchments.

RISK MITIGATION

38. It is important to note that the QMRA results presented here are for attributable risk; i.e., the increment in risk associated with the treated wastewater discharges only. The results do not account for urban and rural stormwater runoff, which will add to the

potential health risks from overflows, but do not form part of the Application. As such, the results presented refer to the enteric and respiratory health risks[10] as a result of the WWTP discharges (which are below the NOAEL at a number of sites). Actual health risks could potentially be higher than NOAEL when urban and rural stormwater runoff discharges are considered. However, as noted above, the QMRA has provided a very conservative assessment, with a number of assumptions including that the QMRA was achieved by accounting for extremely high influent virus concentrations that occur during on-going but undetected viral illness outbreaks in the community; applying a bioaccumulation factor to shellfish virus concentrations; and including a dilution-only scenario that does not include solar ultraviolet-based inactivation of viruses.

39. While results of the health risk assessment show that enterococci in the current Kohukohu WWTP discharge with a worst-case (95th percentile) concentration of 24,400 CFU/100mL does not negatively impact recreational water quality, there would be elevated levels of FIB in the receiving water as a result of the discharge should there be occasional overflows from the WWTPs.

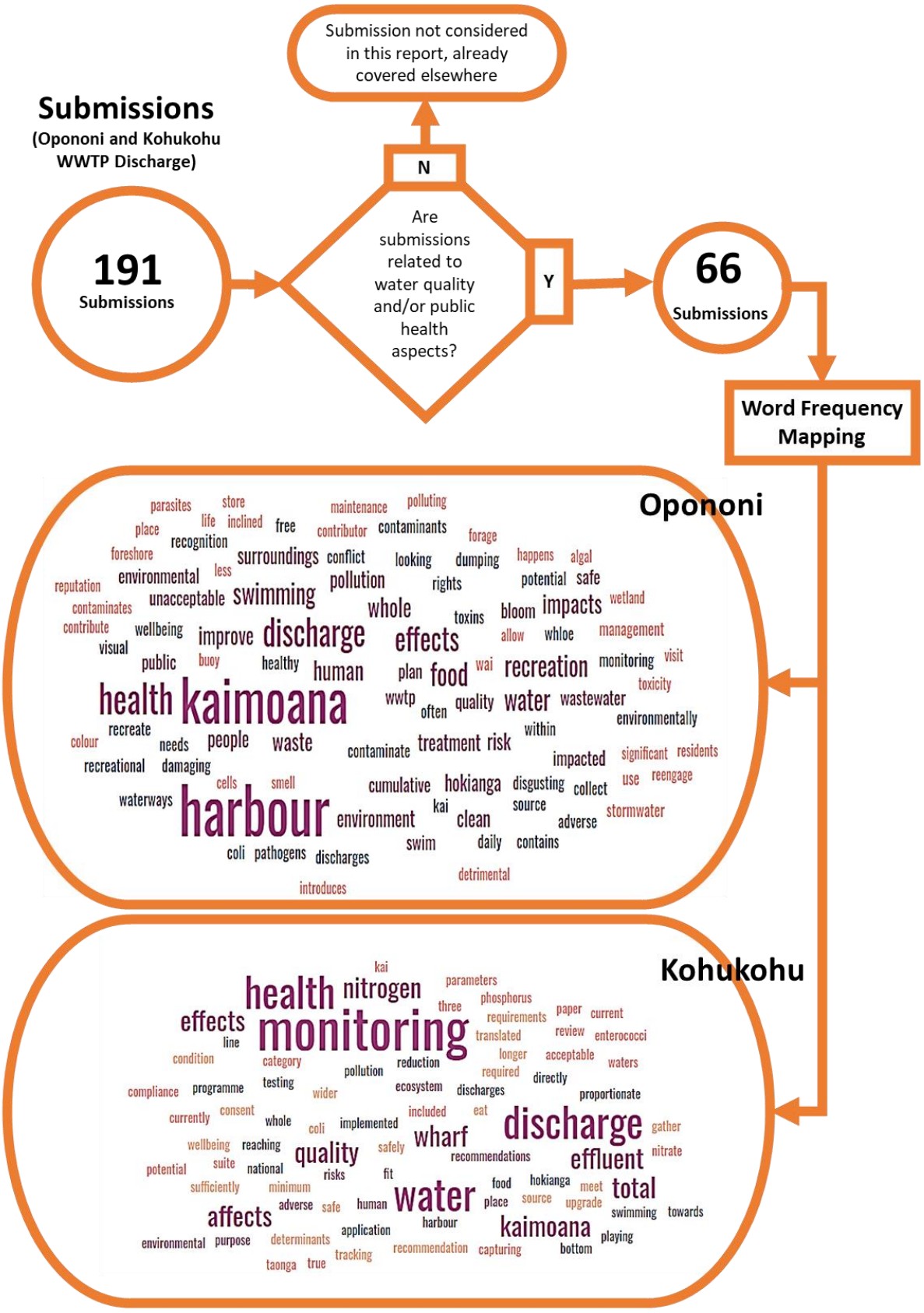
40. Studies have reported that viruses can persist for several weeks or months in the shellfish gut and the environment (Caballero et al 2004, Loisy et al 2005), although large uncertainties surround whether or not they retain their infectivity for this period (Lees 2000, Greening 2007).

41. 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 (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 cannot 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).

[10] associated with ingestion and inhalation during recreational water use

RESPONSE TO ISSUES RAISED IN SUBMISSIONS

42. A total of 191 submissions were received on these applications. Out of these, 66 specifically include concerns related to public health and water quality.



43. Word frequency mapping analysis of the submissions show that concerns focus primarily on the following:

(a) Unacceptability of the discharge of wastewater into the harbour

(b) Concerns regarding kaimoana quality

(c) Concerns regarding water quality and usability of the water for swimming or other recreational purposes

(d) Need for whole harbour approach to health risk assessment

44. I respond to these issues below.

Unacceptability of the discharge of wastewater into the harbour

45. Many submissions oppose the idea of discharging any form of wastewater into the Hokianga Harbour, regardless of whether it has been treated or not. Examples of these submissions are pasted below:

Name	**Summary of submission**
Bruno Watkins	*…unacceptable to discharge wastewater where kaimoana is*
Bruno Watkins	*…unacceptable to discharge wastewater where recreation happens*
Kara Maree Dodson	*…Putting human waste into the harbour is disgusting and disrespectful*
Kelly Ariann Trebilco	*…4 WWTP discharge into the Hokianga*
Manuel Dr Robyn	*…Discharge to water is offensive environmentally*
Mitai Paraone-Kawiti	*…Stop dumping sewage in the harbour as it is a food basket*
Nga Ngaru o Hokianga Takiwa	*……The discharge of human waste to where we collect kaimoana and recreate is unacceptable*
Sandy-lee Bell	*…Not okay to discharge as it's used for recreational use*
Wynard Williams	*…Regardless of treatment it affects Mauri o te wai.*

46. I am not in support of discharge of untreated wastewater into receiving water as it contributes to large amounts of pathogens into receiving waters thus increasing the risks of waterborne illnesses (a position also affirmed in published literature e.g., Fleisher et al., 1996; Shuval, 2003). Notwithstanding, safely managed and properly treated wastewater can be safely returned to the environment. I also understand that issues around alternative discharge mechanisms have been covered elsewhere, and

are outside the scope of this brief which focuses mainly on health risk associated with shellfish consumption and recreational activities in waters receiving treated wastewater.

47. I am however aware that there may be occasional events when 2-log virus reduction is not achieved. Such events can cause negative environmental consequences, including beach closures, contaminated shellfish unsafe for consumption, and contamination of recreational water bodies. During this period, there would be moderate to high health risks associated with the discharge of untreated wastewater. FNDC has advised that the frequency of occurrence of these events, is an average of 3 times per year (based on 2021 and 2022 data provided by FNDC). I recommend that FNDC continues to invest in infrastructural improvements that will further reduce the frequency and volume of overflow events, as this is the best way to minimise risk.

Kaimoana quality

48. Some submissions have indicated their concerns on the perceived current and/or potential effect of the discharges on the quality of food gathered from the Hokianga Harbour. These comments are captured in the table below.

Name	**Summary of submission**
Anna Josephine Bercich	*Potential to contaminate food*
Anna Josephine Bercich	*Potential to contribute to algal bloom, further contaminates kaimoana*
Carbon Neutral Trust NZ	*Affects kaimoana and human health*
Catherine FracnesHackney	*Swimming and Kaimoana affected*
Dr Patricia Margaret le Gal	*Affects harbour life*
Dr Patricia Margaret le Gal	*Effects on kaimoana*
Emily Ashby	*Polluting food store*
Graeme Thomas	*Affects kaimoana*
Hurihia Christine Pomare	*Kaimoana is provided by the harbour*
Judith Margaret Barnes	*Harbour needs to be safe for us to gather kaimoana and recreate*
Judith Reinken	*Kaimoana is impacted*
Kalisha Diamond	*Gathering kai*
Kara Maree Dodson	*Affects cleanliness of the water for recreation and kaimoana*
Kelly Ariann Trebilco	*Only source of food sometimes*
Kiera Jasmine Ellery	*Affects kaimoana and salt making*
Laurence Darcy Brand	*Food, recreation spiritual significance*
Lewis & Melanie Welch	*Impacts swimming and kaimoana*
Louis Toorenburg	*No longer safe to eat kaimoana*
Marama Grace Koroheke	*Pollutes Kai moana*
Maree Nasey	*Affects ability to harvest seaweed*
Maryann Watene	*Affects kiamoana and recreation*
Northland Branch of the Green Party Aotearoa	*Human waste contains pathogens, viruses*
Pamela Browne	*Affects kaimoana*
Pheobe Watkins	*Impacts on food chain*
Pheobe Watkins	*Jeopardises recreation and kaimoana*
Rangi Tuoro	*access to clean water and food impacted*
Rebecca Thorne	*Swimming and Kaimoana affected*
Seabourne Rust and Diane Yanakopuloa	*Environmentally damaging*
Shannon Mary-Leigh Marsh	*Kaimoana and recreation is affected*

Stephen Jon Heim	*Worry about eating potentially contaminated food*
Suzanne Lesley Duff	*Local people swim and collect kaimoana and there is a risk of infection from contamination*
Therese Burgess	*Kaimoana is negatively impacted*
Wairere Covich	*Kaimoana and recreation is affected*
Wynard Williams	*affects swimming, kaimoana, fishing*

49. Objectively, the key question that arises from these submissions is:

Are individuals likely to get sick after consuming raw shellfish harvested from the water?

50. This question has been addressed in the First Report which examined health risks associated with the consumption of food gathered from Hokianga Harbour. Like other NZ QMRAs, because shellfish has the potential to be accidentally or intentionally consumed raw, the First Report focussed on shellfish when assessing health risks associated with consumption of seafood. Like previous QMRA reports (e.g. McBride 2016 a, b), we 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, and are very frequently consumed raw. Additionally, because shellfish are known to 'bioaccumulate' pathogens (Bellou, Kokkinos, and Vantarakis 2013; Hanley 2015; Hassard et al. 2017), an additional multiplier effect called the pathogen bioaccumulative factor (PBAF, see Table 3) was included in the risk assessment, consistent with previous NZ QMRAs (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al 2017).

51. The QMRA modelling results for shellfish harvesting and consumption show that if a 1-log virus reduction for norovirus and enterovirus is achieved during wastewater treatment by the contributing WWTPs, because of high levels of dilution occurring in the harbour, only low illness risks are associated with consumption of raw shellfish at all sites.

52. However, if a 2-log reduction in enterovirus and norovirus concentrations is achieved at the WWTPs before discharge, QMRA modelling results show that enteric illness risks among individuals who consume raw shellfish collected at the shellfish harvesting sites are reduced to below the NOAEL at all the exposure sites.

53. I note however that the range of log reduction achieved in the current wetland-based treatment system at Opononi WWTP is not known, as there is no virus monitoring program for discharge water quality. Literature reveal that the performance of constructed wetland systems used for wastewater treatment will vary depending on the

presence and type of plants, filter depth and sand type, operational parameters, temperature effects and retention time (Quiñónez-Dìaz et al 2001). Notwithstanding, a summary of virus removals reported in available literature suggest that 2log virus removals is the most predominantly reported level of reduction in virus concentrations in wetlands.

54. Therefore, the level of treatment currently applied at the Opononi WWTP (if its virus reduction performance is consistent with the literature, i.e. an average 2log virus removal) has been shown by the QMRA modeling to be sufficient to reduce illness risks associated with recreation or consumption of harvested raw shellfish below the "no observable adverse effect level" (**NOAEL**).

Recreational water quality

55. Some submissions have indicated their concerns in relation to the perceived current and/or potential effect of the discharge on the quality of water available for recreational use in the Hokianga harbour. These comments are captured in the table below.

Name	**Summary of submission**
Craig and Kirsty Joiner	Less inclined to swim and forage on foreshore
Daniel Pennington	Allow harbour to improve its health
Graeme Thomas	In conflict with rights to clean and healthy environment
Janine Elizabeth McVeagh	Adverse environmental effects
Jessie McVeagh & Kahu Jack McVeagh Nathan	Risks to human health and ecosystem health - discharge directly affects water quality
Joe Tuoro	Adverse impacts on health of the environment and people
Kelly Ariann Trebilco	Unsafe for swimming
Louis Toorenburg	Visual discharge 'bloom' daily within Harbour
Michael John Albrecht	Broken pipe means wastewater likley to contaminate beaches
Ngai Tupoto Marae Trustees	Impacts recreational values
Rangi Tuoro	Harming waterways, increased no swimming signs
Robin Ian Anderson	Public health effects. Harbour often unsuitable for swimming
Roger Brand	no recognition of the need to improve water quality
Te Rūnanga o Te Rarawa	There is risk of disease through domestic use
Vicki Carpenter	Adverse environmental effects
Dr Patricia Margaret le Gal	Affects reputation as a clean place to visit
Dr Patricia Margaret le Gal	Affects residents
Georgina Garon	Public health damaging
Janice Irene Barratt	Affects mental health and wellbeing
Kalisha Diamond	Adding more sickness on top of pandemic
Kalisha Diamond	General environmental concerns
Kalisha Diamond	Hokianga Harbour is being destroyed
Louis Toorenburg	No longer safe to swim at Pioneer Walk

56. These concerns have already been addressed in the QMRA modelling.

57. QMRA results show that the treated wastewater discharge is not negatively impacting the receiving water quality. The QMRA modelling has shown that that 2-log (i.e. 100-fold) virus reduction typical of the wetland treatment system at the Opononi WWTP discharge by reduce health risks associated with the discharge (in relation to inhalation and ingestion during swimming and consumption of shellfish harvested) at all exposure sites, to levels below the NOAEL. This is due to the very high level of dilution that occurs in the receiving environment, as have been shown in the three-dimensional hydrodynamic modelling conducted by MetOcean.

58. The First Report, which shows that current treated wastewater discharges are not negatively impacting the receiving water quality at all sites in the Hokianga Harbour, also aligns with the generally low FIB concentrations of the receiving environment water samples. For instance:

    (a) Available water quality data for the CR3-SF3 site (i.e. Omapere at Old Wharf Road, downstream of the Opononi WWTP discharge) and Hokianga Harbour Opononi LAWA (upstream of the Opononi WWTP discharge) sites indicates that only low health risk exists at these sites if used for recreational bathing. For instance, the 5-year 95th percentile enterococci concentration for Omapere at Old Wharf Road and Hokianga Harbour Opononi are 52 enterococci/100 mL and 70 enterococci/100 mL, respectively. These concentrations are marginally above the threshold for sites classified as A in terms of the Microbiological Assessment Category (MAC) guidelines (MfE/MoH 2003), hence are classified as B[11].

    (b) Also, at Site CR1 (Upstream of the Opononi WWTP discharge where backwards tidal movement has the potential to wash up discharge, and closest to the Hokianga Harbour Opononi LAWA site where NRC conducts routine microbiological monitoring of recreational water quality), only two samples out of the last 67 monthly water samples collected between 2015 and 2019 exceeded acceptable enterococci concentrations of 140 enterococci/100 mL (Green mode, see lower image in Figure 3). This indicates that in terms of

[11] In terms of the Microbiological Assessment Category (MAC) guidelines (MfE/MoH 2003), enterococci <40 cells/mL =Band A, >40 and <200 cells/mL =Band B, >200 and <500 cells/mL =Band C and >500 cells/mL = Band D

recreation, the water at Hokianga Harbour Opononi LAWA site was generally of acceptable quality and was not being impacted by the WWTP discharges.

59. I note however that there would be moderate health risks associated with the occasional discharge of untreated wastewater that occurs during extreme events. This was reflected in the enterococci data routinely collected by the NRC at CR3-SF3 site. For instance, enterococci concentrations at CR3-SF3 site generally did not exceed the acceptable single sample threshold of 140 enterococci/100 mL (Green mode, see upper image in Figure 3), except in one instance on the 3rd of December 2018 when a lot of stormwater was released onto the beach (observed concentration on storm event day = 680 enterococci/100 mL).

60. In the event of future spills, risk management efforts should include notification of the District Medical Officer of Health, erection of temporary warning signs at swimming and recreation sites, and release of information to advise members of the public to avoid the use of these sites for recreational purposes at least 48 hours after an overflow event or heavy rainfall. These efforts are highly effective with respect to mitigating risks associated with primary and secondary contact recreation.

Issues around monitoring of recreational water quality

61. Three submissions raised concerns regarding the insufficiency of monitoring of receiving water quality.

"*Not monitoring viral contaminants*"…. Michael John Albrecht
"*Insufficient regular ongoing testing of waters*"….. Sandy-lee Bell
"*Monitoring for E.coli and pathogens is infrequent*"… Suzanne Lesley Duff

62. As part of Northland Regional Council's coastal monitoring exercise, NRC conducted a limited short-term monitoring of water quality at several sites within the vicinity of the discharges in the Hokianga Harbour. This monitoring focused on 16 sites in the Hokianga Harbour between June 2009 and June 2010 (Figure 4).

63. Samples were analysed monthly for FIB (E. coli, enterococci and faecal coliforms) and concentrations compared to available MfE/MoH guidelines. While results showed a high level of compliance with the relevant guidelines, I agree that the frequency of this monitoring should be maintained, should consent be granted. This will help authorities and relevant stakeholders keep an eye on the quality of water in the receiving water environment.

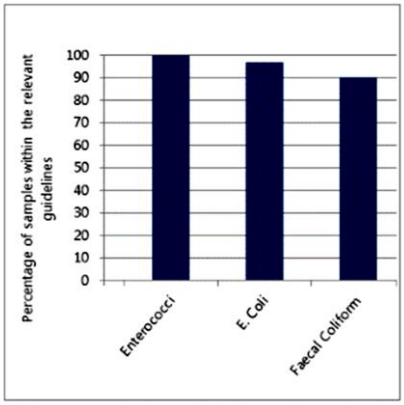


Figure 1. Hokianga Harbour water quality compliance results (2009-2010).

64. I am also aware that the Northland Regional Council has routinely monitored other LAWA bathing sites, including coastal sites that are upstream and downstream of the Opononi WWTP (i.e. Hokianga Harbour Opononi and Omapere at Old Wharf Road, respectively). While data at the Omapere at Old Wharf Road site has only been collected since 2018 till date, enterococci data has since 2009 been collected at the Hokianga Harbour Opononi site. Results of these water quality monitoring are already discussed in paragraphs 58(a) to 59.

65. Two submissions called for virus and/or pathogen monitoring of the receiving water environment for the purpose of routine surveillance. To address this, I will cover two aspects of the concerns:

(a) general call for pathogen monitoring of the receiving water environment for the purpose of routine surveillance, and specifically,

(b) the call for routine virus monitoring of the receiving water environment.

66. Because of a wide plethora of potential pathogens and typically low concentrations in environmental waters, direct monitoring of waterborne pathogens could be very expensive, technically challenging, and in some instances, unfeasible. Typically for the purpose of routine surveillance, recreational waters are therefore monitored for FIB (faecal coliforms, Escherichia coli and enterococci) levels instead (Korajkic et al 2018). The resulting FIB concentrations could then be used to potentially estimate whether the water body is safe for human recreational contact, and the resulting data are used to determine whether beach advisories or closures are needed (European Environment Agency 2006, MfE, 2000).

67. As with the complexity associated with other pathogen detection, virus detection in aquatic environments such as wastewater, sewage, and drinking water requires techniques that allow rapid detection and are highly sensitivity, reliable, reproducible, representative, and cost-effective (Pilevar et al 2021). Added to these high standards are the high variability of viral presence in natural bodies of water/ wastewater samples which tend to make the development of standardized viral detection methods a challenge (Javier E. Sanchez-Galan et al 2021). Added to this are complexities around the differential persistence of nucleic acid markers of health-relevant organisms in seawater microcosms and its implications for recreational water risk decision-making. For instance, PCR-based methods used to enumerate viruses from environmental samples tend to detect nucleic acids from both living and dead particles or from both infectious and noninfectious virus particles which can lead to difficulties in interpretation (Ceuppens et al 2014, Walters et al 2009). Studies have also shown that DNA and RNA from enterococci and enterovirus persisted for over 10 d in environmental matrixes. Given these complexities, I do not recommend that an environmental monitoring program be based on the routine detection of viruses in the receiving environment.

Need for whole harbour approach to health risk assessment

68. Other submissions raised concerns about the need for a whole harbour approach to health risk assessment and management. Extracts of these submissions are pasted below:

Name	Summary of submission
Darleen Sheree Tana	Cumulative effects on whole harbour
Fiona Marlene Murray	Pollution affects the whole harbour and surroundings
Georgina Matika	Pollution affects the whole harbour and surroundings
Janine Elizabeth McVeagh	Should be looking at the effects on the harbour as a whole
Jessie McVeagh & Kahu Jack McVeagh Nathan	Cumulative effects on whole harbour
Lou Taumanui Matika	Pollution affects the whole harbour and surroundings
Louis Toorenburg	Hokianga is dumping ground for nearly half the population
Michael John Albrecht	Should be looking at the effects on the harbour as a whole
Northland Branch of the Green Party Aotearoa	Discharge from four WWTP has an accumulation effect
Paul Bowker	Further discharge volume created by diversion of waste from kaikohe
Pauline Bellerby	Health of the harbour is not good
Te Mauri o Te Wai	Towards a holistic and integrated management approach
Te Rūnanga o Te Rarawa	Improve the health of the wai by adress stormwater and non-point source discharges as is the responsibility of FNDC
Te Rūnanga Papa Atawhai o Te Tai	Stormwater needs to be addressed

Tokerau (Northland Conservation Board	
Te Tu Tika Rohe Moana of Te Hikutu Hapu	Needs catchment management plan
Tony Flavell	Pollution affects the whole harbour and surroundings
Vicki Carpenter	Cumulative effects need to be considered

69. I agree that an whole harbour/whole catchment approach needs to be applied to manage pollution and concomitant health risks associated with pollutant discharge from all point and non-point sources.

70. FNDC has been proactive in applying a whole harbour approach to assessing health risks associated with the WWTP discharge by:

(a) Commissioning a three-dimensional hydrodynamic modelling to examine the response of the entire harbour to the wastewater discharges, including considerations for tidal movement into and out of the harbour. The three-dimensional modelling has shown that during conditions of backflushing of tidal waves back into the Harbour, the dilution in the receiving environment is very high (for example 95th percentile dilution at Site CR1 is 230,000 and 134,000 during el nino and la nina conditions), given the small amount of the discharge and the large amount of water available for mixing in the Hokianga Harbour.

(b) Commissioning a QMRA study that assesses risks from the Opononi WWTP but using dilutions obtained during a scenario that all four WWTPs discharging into the harbour were simultaneously "turned on", such that the effect modelled at exposure sites in the First Report also captured additional effects from the other WWTPs which are all upstream of the Opononi WWTP. This precautionary and conservative approach applied in the First Report, therefore, captures the cumulative effect of all WWTPs in the Hokianga harbour. Other precautionary and conservative approaches in the QMRA was achieved by accounting for extremely high influent virus concentrations that occur during on-going but undetected viral illness outbreaks in the community; including a dilution-only scenario that does not include solar ultraviolet-based inactivation of viruses; and applying a bioaccumulation factor to shellfish.

71. While these efforts are a step in the right direction, I agree with the concerns raised in the submissions that efforts aimed at addressing pollution in the Hokianga Harbour need to be integrated and catchment-wide. This is particularly so because other potential contaminant sources (such as urban runoff, streams draining catchments etc.)

may impair water quality during storm events. Additionally, the QMRA results presented are for attributable risk, i.e., the increment in risk associated with the four WWTP. Hence, it does not include risks associated with other sources e.g., overflows or stormwater runoff from catchment sources, re-suspension of bacteria-rich sediment during rough weather conditions, contributions from wild animals e.g. seabirds, livestock effluent, sewage overflows, and faulty or poorly maintained septic tank systems in the catchment.

SUMMARY AND CONCLUSIONS

72. The QMRA approach has been conservative (i.e. more protective) in its approach. The elements of conservatism are noted in my evidence, including the adoption of a precautionary approach where all four WWTPs discharging into the harbour were simultaneously "turned on", such that the effect modelled at exposure sites in the QMRA for Opononi WWTP also captured additional effects from WWTPs upstream of the Opononi WWTP. This precautionary and conservative approach therefore captures the cumulative effect of all WWTPs in the Hokianga Harbour. Other precautionary and conservative approaches in the QMRA was achieved by accounting for extremely high influent virus concentrations that occur during on-going but undetected viral illness outbreaks in the community; including a dilution-only scenario that does not include solar ultraviolet-based inactivation of viruses; and applying a bioaccumulation factor to shellfish.

73. QMRA results show that wastewater treatment that reduces virus concentrations in the WWTP discharge by 2-log (i.e. 100-fold) reduction will reduce health risks associated with the discharge (in relation to inhalation, ingestion during swimming and consumption of shellfish harvested) at all exposure sites, to levels below the NOAEL.

74. In published literature, a 2log virus removal is the most predominantly reported level of reduction in virus concentrations in constructed wetland treatment systems. In line with the QMRA results, if the wetland treatment system is achieving a 2log virus removal, the level of treatment currently applied at the Opononi WWTP is sufficient to reduce illness risks associated with recreation or consumption of harvested raw shellfish below the NOAEL.

75. In the Second Report I assessed recreational health risk due to the Kohukohu WWTP discharge. Results show that enterococci in the current Kohukohu WWTP discharge with a worst-case (95th percentile) concentration of 24,400 CFU/100mL does not

negatively impact recreational water quality. Additionally, enterococci concentrations at all the 12 upstream and downstream sites following the discharge of treated wastewater did not exceed the 140 CFU/100mL limit specified for "Acceptable/Green (surveillance) Mode" in the MfE/MoH (2003) policy document.

76. The current quality of shellfish at the Hokianga sites does not meet the New Zealand Food Safety Authority (NZFSA) 2006 guidelines. However, based on dilutions achieved at the Hokianga Harbour after the discharge, attributable health risks associated with the discharge are below the NOAEL.

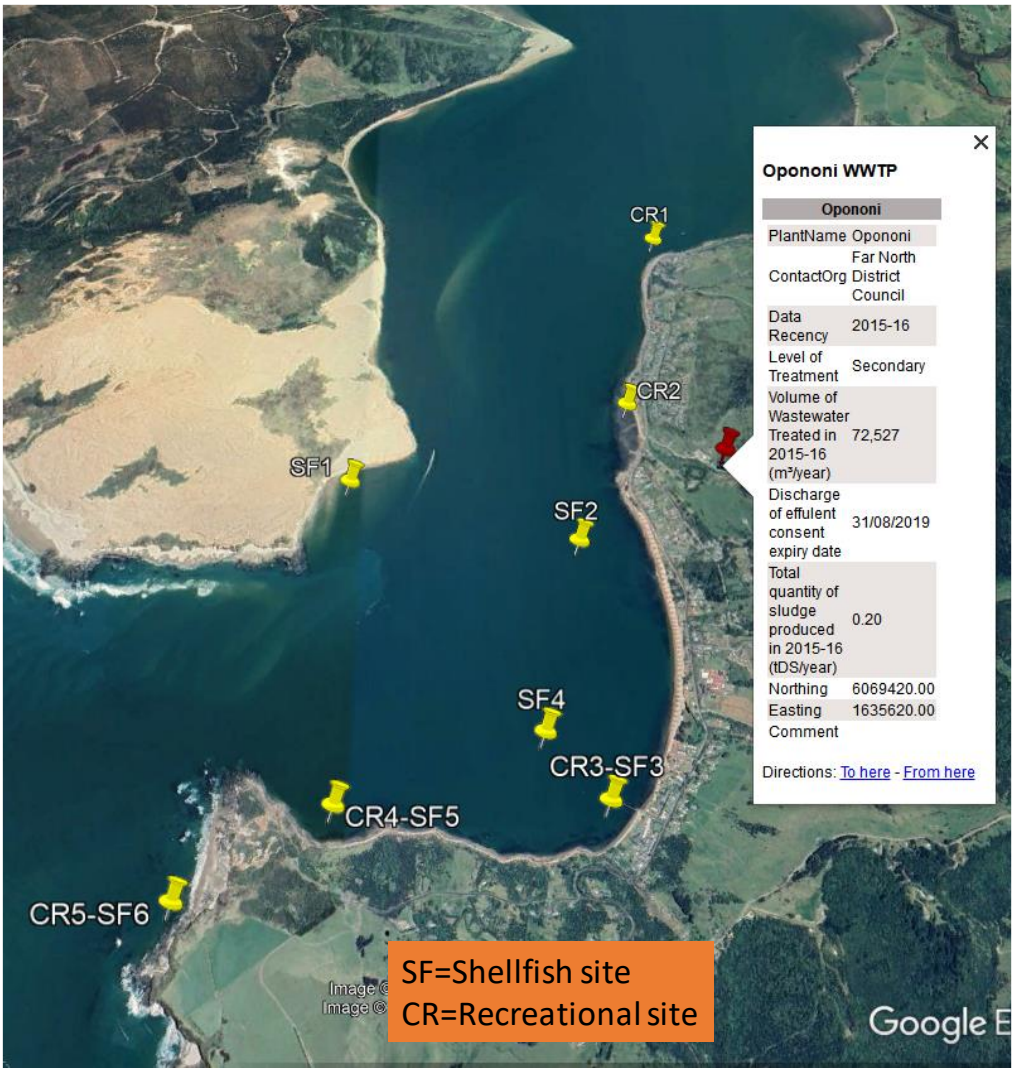
77. Other sources may provide elevated *E. coli* concentrations in shellfish, including re-suspension of bacteria-rich sediment during rough weather conditions, contributions from wild animals e.g. seabirds, livestock effluent, sewage overflows, and faulty or poorly maintained septic tank systems in the catchment. A faecal source tracking study should be commissioned to determine the cause of elevated shellfish tissue *E. coli* concentrations in the Hokianga Harbour. This would assist in managing health risks associated with other inputs unrelated to this Application, including closed landfills, urban and agricultural runoff. This approach was successfully adopted in the Northland Region and ended up associating elevated *E. coli* concentrations in shellfish harvested from the Whangaroa Harbour with faecal sources of contamination that were generally ruminant (herbivore) and wildfowl (Reed, 2011).

78. I agree with the Council officer's position in relation to Kohokohu WWTP that the existing consent limit for faecal coliform should be reduced to further protect shellfish-gathering waters in the receiving environment, given background concentrations.

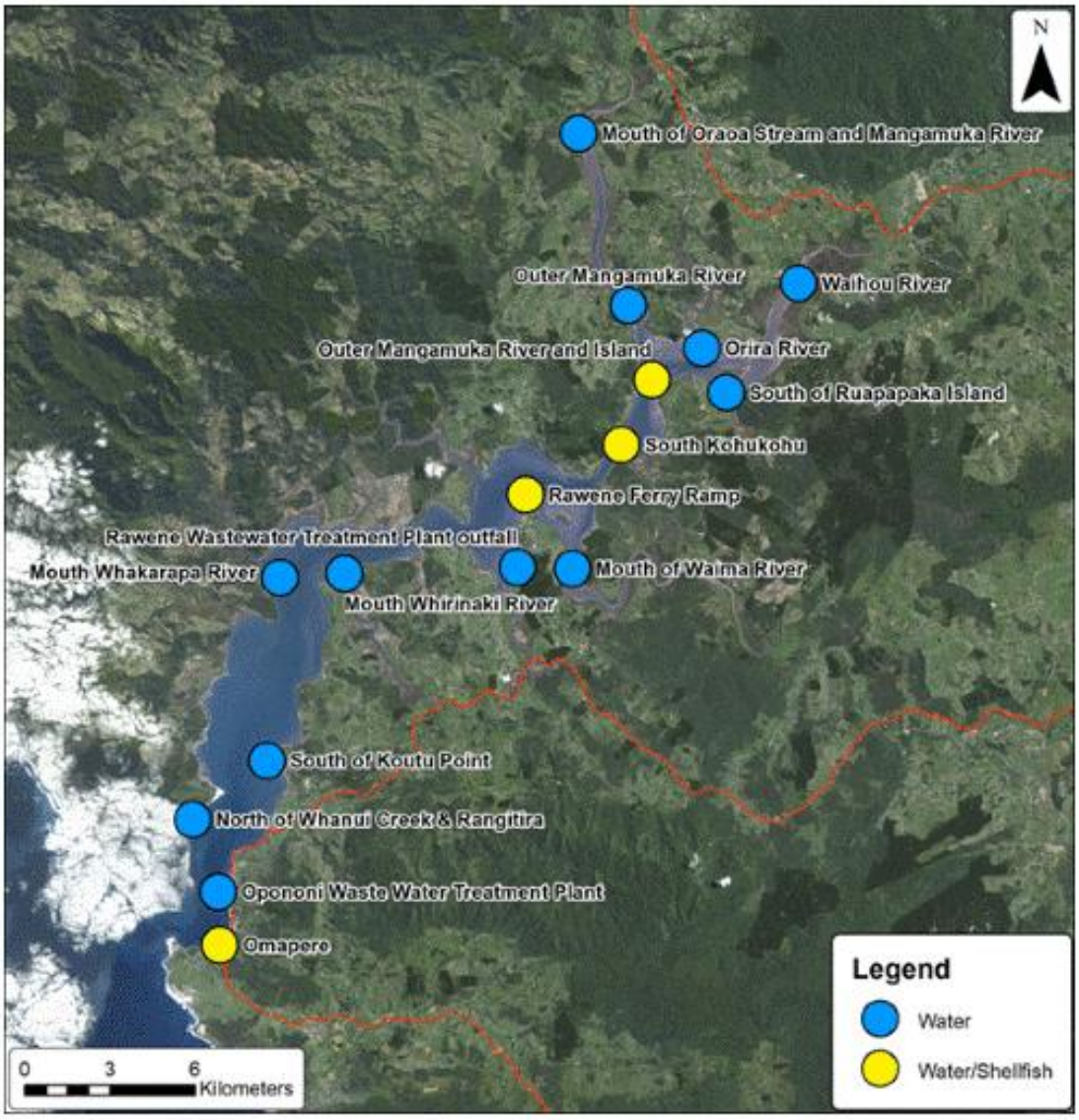
Dr Christopher Ayokunle Dada

3 May 2023

APPENDIX 1: MAP OF LOCATIONS AT WHICH HEALTH RISKS WERE MODELLED



APPENDIX 2: NRC Hokianga Harbour water quality monitoring sites (June 2009-2010).



APPENDIX 3: REFERENCES CITED

Araud, E., DiCaprio, E., Ma, Y., Lou, F., Gao, Y., Kingsley, D., ... & Li, J. (2016). Thermal inactivation of enteric viruses and bioaccumulation of enteric foodborne viruses in live oysters (Crassostrea virginica). *Applied and environmental microbiology*, *82*(7), 2086-2099.

Beaudequin, D. A. (2016). *Modelling the public health risks associated with environmental exposures: A case study in wastewater reuse* (Doctoral dissertation, Queensland University of Technology).

Bellou, M, P Kokkinos, and A Vantarakis 2013 Shellfish-Borne Viral Outbreaks: A Systematic Review. Food and Environmental Virology 5(1): 13–23.

Caballero, S., Abad, F. X., Loisy, F., Le Guyader, F. S., Cohen, J., Pintó, R. M., & Bosch, A. (2004). Rotavirus virus-like particles as surrogates in environmental persistence and inactivation studies. *Applied and environmental microbiology*, *70*(7), 3904-3909.

Ceuppens, S., Li, D., Uyttendaele, M., Renault, P., Ross, P., Ranst, M. V., ... & Donaghy, J. (2014). Molecular methods in food safety microbiology: interpretation and implications of nucleic acid detection. Comprehensive Reviews in Food Science and Food Safety, 13(4), 551-577.

Chávez-Díaz, L. V., Gutiérrez-Cacciabue, D., Poma, H. R., & Rajal, V. B. (2020). Sediments quality must be considered when evaluating freshwater aquatic environments used for recreational activities. *International journal of hygiene and environmental health*, *223*(1), 159-170.

Chávez-Díaz, L. V., Gutiérrez-Cacciabue, D., Poma, H. R., & Rajal, V. B. (2020). Sediments quality must be considered when evaluating freshwater aquatic environments used for recreational activities. *International journal of hygiene and environmental health*, *223*(1), 159-170.

Dada, A. C., & Gyawali, P. (2021). Quantitative microbial risk assessment (QMRA) of occupational exposure to SARS-CoV-2 in wastewater treatment plants. *Science of The Total Environment*, *763*, 142989.

Dada, A.C. (2018b) Quantitative Microbial Risk Assessment for the discharge of treated wastewater at Army Bay. Report WSL1701, Streamlined Environmental, Hamilton, 73 pp.

Danovaro, R., and Middelboe, M. (2010). "Separation of free virus particles from sediments in aquatic systems," in *Manual of Aquatic Viral Ecology*, eds S. W. Wilhelm, M. G. Weinbauer, and C. A. Suttle (Washington, DC: ASLO), 74–81.

Danovaro, R., Dell'anno, A., Trucco, A., Serresi, M., and Vanucci, S. (2001). Determination of virus abundance in marine sediments. *Appl. Environ. Microbiol.* 67, 1384–1387. doi: 10.1128/AEM.67.3.1384-1387.2001

Dean, K.; Mitchell, J. A dose response model for the inhalation route of exposure to P. aeruginosa. Microb. Risk Anal. 2020, 15, 100115. [CrossRef]

Dong, P., Cui, Q., Fang, T., Huang, Y., & Wang, H. (2019). Occurrence of antibiotic resistance genes and bacterial pathogens in water and sediment in urban recreational water. *Journal of Environmental Sciences*, *77*, 65-74.

Dufour, A.P.; Evans, O.; Behymer, T.D.; Cantú, R. (2006). Water ingestion during swimming activities in a pool: A pilot study. Journal of Water Health 4(4): 425–430.

Dupont, H.L.; Formal, S.B.; Hornick, R.B.; Snyder, M.J.; Libonati, J.P.; Sheahan, D.G.; LaBrec, E.H.; Kalas, J.P. Pathogenesis of Escherichia coli Diarrhea. N. Engl. J. Med. 1971, 285, 1–9

Esfahanian, E.; Adhikari, U.; Dolan, K.; Mitchell, J. Construction of a new dose–response model for Staphylococcus aureus considering growth and decay kinetics on skin. Pathogens 2019, 8, 253.

Esiobu, N., Mohammed, R., Echeverry, A., Green, M., Bonilla, T., Hartz, A., ... & Rogerson, A. (2004). The application of peptide nucleic acid probes for rapid detection and enumeration of eubacteria, Staphylococcus aureus and Pseudomonas aeruginosa in recreational beaches of S. Florida. *Journal of microbiological methods*, *57*(2), 157-162.

European Environment Agency. Directive 2006/7/EC of the European Parliament and of the Council of February 2006 Concerning the Management of Bathing Water Quality and Repealing Directive 76/160/EEC; European Environment Agency: Geneva, Switzerland, 2006.

Fewtrell, L., & Kay, D. (2015). Recreational water and infection: a review of recent findings. Current environmental health reports, 2(1), 85-94.

Fleisher, J. M., & Kay, D. (2006). Risk perception bias, self-reporting of illness, and the validity of reported results in an epidemiologic study of recreational water associated illnesses. *Marine Pollution Bulletin*, *52*(3), 264-268.

Fleisher, J. M., & Kay, D. (2006). Risk perception bias, self-reporting of illness, and the validity of reported results in an epidemiologic study of recreational water associated illnesses. *Marine Pollution Bulletin*, *52*(3), 264-268.

Fleisher, J. M., Fleming, L. E., Solo-Gabriele, H. M., Kish, J. K., Sinigalliano, C. D., Plano, L., ... & Backer, L. C. (2010). The BEACHES Study: health effects and exposures from non-point source microbial contaminants in subtropical recreational marine waters. *International journal of epidemiology*, *39*(5), 1291-1298

Fleisher, J. M., Kay, D., Salmon, R. L., Jones, F., Wyer, M. D., & Godfree, A. F. (1996). Marine waters contaminated with domestic sewage: nonenteric illnesses associated with bather exposure in the United Kingdom. *American journal of public health*, *86*(9), 1228-1234.

Goldstein, R. E. R., Micallef, S. A., Gibbs, S. G., Davis, J. A., He, X., George, A., ... & Sapkota, A. R. (2012). Methicillin-resistant Staphylococcus aureus (MRSA) detected at four US wastewater treatment plants. *Environmental Health Perspectives*, *120*(11), 1551-1558.

Graciaa DS, Cope JR, Roberts VA, et al. Outbreaks Associated with Untreated Recreational Water — United States, 2000–2014. MMWR Morb Mortal Wkly Rep 2018;67:701–706. DOI: http://dx.doi.org/10.15585/mmwr.mm6725a1external icon.

Greening (2007) NLRC Shellfish safety following sewage spills. Environlink report No. 162 NLRC20 May 2007. Available online: https://envirolink.govt.nz/assets/Envirolink/162-nlrc20.pdf

Grodzki M, Schaeffer J, Piquet JC, et al. Bioaccumulation efficiency, tissue distribution, and environmental occurrence of hepatitis E virus in bivalve shellfish from France. Appl Environ Microbiol. 2014;80(14):4269-4276. doi:10.1128/AEM.00978-14

Haile, R. W., Witte, J. S., Gold, M., Cressey, R., McGee, C., Millikan, R. C., ... & Wang, G. Y. (1999). The health effects of swimming in ocean water contaminated by storm drain runoff. *Epidemiology*, 355-363.

Hanley, Kaitlyn Terese 2015 Human Noroviruses in the Coastal Environment: Association with Aquatic Macroaggregates and the Risk of Infection by Raw Shellfish Consumption. University of California, Davis.

Hassard, Francis, Jasmine H Sharp, Helen Taft, et al. 2017 Critical Review on the Public Health Impact of Norovirus Contamination in Shellfish and the Environment: A UK Perspective. Food and Environmental Virology 9(2): 123–141.

Hudson, N (2019) Wastewater overflow discharge consent - Queenstown Lakes District Council Microbial risk assessment. Report: BEC19201

Korajkic, A., McMinn, B. R., & Harwood, V. J. (2018). Relationships between microbial indicators and pathogens in recreational water settings. *International Journal of Environmental Research and Public Health*, *15*(12), 2842.

Korajkic, Asja, Brian R. McMinn, and Valerie J. Harwood. 2018. "Relationships between Microbial Indicators and Pathogens in Recreational Water Settings" International Journal of Environmental Research and Public Health 15, no. 12: 2842. https://doi.org/10.3390/ijerph15122842

Kozak, S., Petterson, S., McAlister, T., Jennison, I., Bagraith, S., & Roiko, A. (2020). Utility of QMRA to compare health risks associated with alternative urban sewer overflow management strategies. *Journal of environmental management*, *262*, 110309.

Kusumawardhana, A., Zlatanovic, L., Bosch, A., & van der Hoek, J. P. (2021). Microbiological Health Risk Assessment of Water Conservation Strategies: A Case Study in Amsterdam. International Journal of Environmental Research and Public Health, 18(5), 2595.

Lees, D. (2000). Viruses and bivalve shellfish. *International journal of food microbiology*, *59*(1-2), 81-116.

Leonard, A. F., Singer, A., Ukoumunne, O. C., Gaze, W. H., & Garside, R. (2018). Is it safe to go back into the water? A systematic review and meta-analysis of the risk of acquiring infections from recreational exposure to seawater. *International journal of epidemiology*, *47*(2), 572-586.

Liang, L., Goh, S. G., Vergara, G. G. R. V., Fang, H. M., Rezaeinejad, S., Chang, S. Y., ... & Gin, K. Y. H. (2015). Alternative fecal indicators and their empirical relationships with enteric viruses, Salmonella enterica, and Pseudomonas aeruginosa in surface waters of a tropical urban catchment. *Applied and environmental microbiology*, *81*(3), 850-860.

Loisy, F., Atmar, R. L., Le Saux, J. C., Cohen, J., Caprais, M. P., Pommepuy, M., & Le Guyader, F. S. (2005). Use of rotavirus virus-like particles as surrogates to evaluate virus persistence in shellfish. *Applied and environmental microbiology*, *71*(10), 6049-6053.

López, A., Rodríguez-Chueca, J., Mosteo, R., Gómez, J., Rubio, E., Goñi, P., & Ormad, M. P. (2019). How does urban wastewater treatment affect the microbial quality of treated wastewater?. *Process Safety and Environmental Protection*, *130*, 22-30.

Maalouf, H., Schaeffer, J., Parnaudeau, S., Le Pendu, J., Atmar, R. L., Crawford, S. E., & Le Guyader, F. S. (2011). Strain-dependent norovirus bioaccumulation in oysters. *Applied and Environmental Microbiology*, *77*(10), 3189-3196.

McBride, G. 2016a Quantitative Microbial Risk Assessment for the Discharge of Treated Wastewater: Warkworth Wastewater Treatment Plan. Report Prepared by NIWA for Watercare Services Limited. HAM2016-037.

McBride, G., 2011. A quantitative microbial risk assessment for Napier City's ocean wastewater discharge.

McBride, G., 2012. An assessment of human health effects for a quantitative approach based on Norovirus. NIWA Client Report No: HAM2012-150, prepared for New Plymouth District Council, Project NPD13202.

McBride, Graham 2007 Microbial Risk Assessment Modeling. Statistical Framework for Recreational Water Quality Criteria and Monitoring: 135–151.

Palmer M. (2014).The importance of the social components of biotransformation in the treatment of wastewater Part 2: Water user experiences, perceptions and aspirations Te Turanganui a KIWA, 2013. Te Turanganui a Kiwa Gisborne Wastewater Technical Advisory Group

Pilevar, M., Kim, K. T., & Lee, W. H. (2021). Recent advances in biosensors for detecting viruses in water and wastewater. Journal of Hazardous Materials, 410, 124656.

Pitol, A.K.; Bischel, H.N.; Kohn, T.; Julian, T.R. Virus Transfer at the Skin-Liquid Interface. Environ. Sci. Technol. 2017, 51, 14417–14425. [CrossRef] 49. Pitol, A.K.; Kohn, T.; Julian, T.R. Retention of E. coli and water on the skin after liquid contact. PLoS ONE 2020, 15, e0238998. [CrossRef]

Rasheduzzaman, M., Singh, R., Haas, C. N., Tolofari, D., Yassaghi, H., Hamilton, K. A., ... & Gurian, P. L. (2019). Reverse QMRA as a decision support tool: Setting acceptable concentration limits for Pseudomonas aeruginosa and Naegleria fowleri. Water, 11(9), 1850.

Rasheduzzaman, M., Singh, R., Haas, C. N., Tolofari, D., Yassaghi, H., Hamilton, K. A., ... & Gurian, P. L. (2019). Reverse QMRA as a decision support tool: Setting acceptable concentration limits for Pseudomonas aeruginosa and Naegleria fowleri. *Water*, *11*(9), 1850.

Rhame, F. S. 1979. The ecology and epidemiology of Pseudomonas aeruginosa, p. 31-51. In L. D. Sabath (ed.), Pseudomonas aeruginosa: the organism, diseases it causes and their treatment. Hans Huber Publishers, Bern, Switzerland

Rhame, F. S. 1979. The ecology and epidemiology of Pseudomonas aeruginosa, p. 31-51. In L. D. Sabath (ed.), Pseudomonas aeruginosa: the organism, diseases it causes and their treatment. Hans Huber Publishers, Bern, Switzerland.

Rose JB and Haas CN (1999) A risk assessment framework for the evaluation of skin infections and the potential impact of antibacterial soap washing. *American Journal of Infection Control* 27(6), S26-S33

Roser, D. J., Van den Akker, B., Boase, S., Haas, C. N., Ashbolt, N. J., & Rice, S. A. (2014). Pseudomonas aeruginosa dose response and bathing water infection. *Epidemiology & Infection*, *142*(3), 449-462.

Sanchez-Galan, J. E., Ureña, G., Escovar, L. F., Fabrega-Duque, J. R., Coles, A., & Kurt, Z. (2021). Challenges to detect SARS-CoV-2 on environmental media, the need and strategies to implement the detection methodologies in wastewaters. Journal of Environmental Chemical Engineering, 9(5), 105881.

Schets, F. M. (2011). *The microbiological safety of bathing water–Waterborne pathogens beyond bathing water legislation*. Utrecht University.

Soller, J. 2008. An introduction to quantitative microbial risk assessment. US EPA 2008 Stakeholders Meeting. Washington DC.

Soller, J. A. 2012. How well does science support the QMRA process – An overview. State-of-the-Science Symposium: Fecal Source Identification and Associated Risk Assessment Tools. Southern California Coastal Water Research Project Authority.

Southern California Coastal Water Research Project.- SCCWRP (2021) Microbial Risk Assessment. Availe at https://www.sccwrp.org/about/research-areas/microbial-water-quality/microbial-risk-assessment/

Stewart, M, Cooke, J, Dada, A.C. (2017) Assessment of ecological effects on the receiving environment associated with the discharge from the proposed membrane bioreactor wastewater treatment system. Option 1: Treatment of all wastewater generated by Te Kauwhata (current and future), Springhill Prison (current and future) and the Lakeside development. Report LDL1701–FINAL, Streamlined Environmental, Hamilton, 168 pp.

Stott R and Hudson, N (2019) Microbial Risk Assessment for Oceania Dairy Limited Assessment of potential human health risk effects from discharge of dairy factory processing wastewaters via an ocean outfall. prepared for Babbage Consulting Limited. August 2019

Streeter, K., & Katouli, M. (2016). Pseudomonas aeruginosa: A review of their Pathogenesis and Prevalence in Clinical Settings and the Environment.

Streeter, K., & Katouli, M. (2016). Pseudomonas aeruginosa: A review of their Pathogenesis and Prevalence in Clinical Settings and the Environment.

Tamrakar, S. Pseudomonas aeruginosa (Contact lens): Dose Response Models - QMRAwiki. Available online: http://qmrawiki.canr.msu.edu/index.php/Pseudomonas_aeruginosa_(Contact_lens):_Dose_ Response_Models#_ada0a7ba80d80d6c03b247607643bf29 (accessed on 23rd May 2021).

Tfaily, R., Papineau, I., Andrews, R. C., & Barbeau, B. (2015). Application of quantitative microbial risk assessment at 17 Canadian water treatment facilities. Journal-American Water Works Association, 107(10), E497-E508.

USGS Laboratory for Infectious Disease and the Environment (n.d) Quantitative microbial risk assessment (QMRA). Availabe at https://www.usgs.gov/centers/umid-water/science/lide-capabilities-quantitative-microbial-risk?qt-science_center_objects=0#qt-science_center_objects

Vasagar, B., Jain, V., Germinario, A., Watson, H. J., Ouzts, M., Presutti, R. J., & Alvarez, S. (2018). Approach to aquatic skin infections. *Primary Care: Clinics in Office Practice*, *45*(3), 555-566.

Walters, S. P., Yamahara, K. M., & Boehm, A. B. (2009). Persistence of nucleic acid markers of health-relevant organisms in seawater microcosms: implications for their use in assessing risk in recreational waters. Water research, 43(19), 4929-4939.

Weaver, L., & Sinton, L. (2009). Deposition and survival of enteric microbes in aquatic sediments—a brief review. *Institute of Environmental Science & Research Ltd, Christchurch*.

Yau, V., Wade, T. J., de Wilde, C. K., & Colford, J. M. (2009). Skin-related symptoms following exposure to recreational water: a systematic review and meta-analysis. *Water Quality, Exposure and Health*, *1*(2), 79-103.

Yau, V., Wade, T. J., de Wilde, C. K., & Colford, J. M. (2009). Skin-related symptoms following exposure to recreational water: a systematic review and meta-analysis. *Water Quality, Exposure and Health*, *1*(2), 79-103.

Yoshpe-Purer, Y. O. N. A., & Golderman, S. (1987). Occurrence of Staphylococcus aureus and Pseudomonas aeruginosa in Israeli coastal water. *Applied and environmental microbiology*, *53*(5), 1138-1141.

Yoshpe-Purer, Y. O. N. A., & Golderman, S. (1987). Occurrence of Staphylococcus aureus and Pseudomonas aeruginosa in Israeli coastal water. *Applied and environmental microbiology*, *53*(5), 1138-1141.

Yu, C.-Y.; Lin, C.-H.; Yang, Y.-H. Human body surface area database and estimation formula. Burns 2010, 36, 616–629