BEFORE THE INDEPENDENT HEARING COMMISSIONERS
FOR GISBORNE DISTRICT COUNCIL

IN THE MATTER: of the Resource Management Act 1991

AND

IN THE MATTER: of an application by Gisborne District Council for resource consent associated with wastewater overflows

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STATEMENT OF EVIDENCE OF DR CHRISTOPHER AYOKUNLE DADA
– QUANTITATIVE MICROBIAL RISK ASSESSMENT
25 June 2021

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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 past/future 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 (2021), I published in the Science of the Total Environment journal on QMRA of occupational exposure to SARS-CoV-2 in wastewater treatment plants.

Code of Conduct

5. 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 2014. 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

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

   (a) My involvement in the Gisborne Wastewater Overflows Resource Consent Application (**Application**);

   (b) Quantitative Microbial Risk Assessment;

   (c) Response to issues raised in submissions;

   (d) Proposed consent conditions including monitoring plans;

   (e) Summary and conclusion.

MY INVOLVEMENT IN THE WASTEWATER OVERFLOW CONSENT PROJECT

7. I became involved in the Gisborne District Council (**GDC or Council**) wastewater overflow project in 2019.

8. As an employee at Streamlined Environmental Limited, I undertook an assessment and produced a Report for GDC titled 'Quantitative Health Risk Assessment for Wet-Weather Wastewater Discharges into City Rivers and Poverty Bay, Gisborne, which was included as Appendix M to the Application.

9. I also provided input into the responses to the s92 request, which was included as Attachment F to the s92 response dated 29 January 2021.

QMRA

10. Quantitative microbial risk assessment (**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 these matters further in relation to the Application in paragraphs 12 to 15 below.

Hazard Identification

12. Hazard identification involves a determination of pathogens and human health outcomes of concern. For environmental waters impacted by wastewater overflows in the Tūranganui-a-Kiwa/Poverty Bay environment, the preferred gastrointestinal pathogens considered for human risk assessment are members of the bacterial genus Salmonella; noroviruses and enteroviruses; and the parasites associated with cryptosporidiosis, giardiasis and ascariasis. Norovirus, enterovirus and adenovirus have been used as representative viruses for several previous WWTP QMRAs in New Zealand (Dada 2018a; 2018b; Dada 2019; McBride 2007, 2011, 2012, 2016; Hudson 2019). The health outcome considered in this QMRA is illness.

Exposure Assessment

13. Exposure assessment involves a determination of the pathways of exposure and measuring or modelling the pathogen exposure doses during defined exposure events. I understand that during heavy rainfall, excessive rainwater/stormwater enters the wastewater network through inflow and infiltration[1]. This can occur from a range of mechanisms including direct entry from roofs (e.g. illegal or damaged gully traps) and overland flow into the wastewater network; and infiltration (e.g. groundwater entry through cracks in the pipe network). I understand that this can cause the capacity of the wastewater network to be exceeded, with the result that GDC opens overflow relief valves to discharge overflows at controlled points into receiving waters (rivers), in order to ensure that uncontrolled overflows do not occur (including on to private property)[2]. At any given point (referred to as an exposure site) in the receiving environment, pathogens in the overflow have the potential to lead to undesirable health outcomes. 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: GDC identified 14 exposure sites where recreation or shellfish gathering is likely to take place. These sites are shown on the map attached as **Appendix 1** to my evidence.

[1] Application at Section 1.2
[2] Application at Section 2.2.4 p10

Site 1 (farthest horizontal distance to discharge along the Centennial Marine Drive shoreline); Sites 2, 3 and 5 (along the Kaiti Beach Road shoreline); Site 4 (close to Wainui Road and the outlet of the discharge into the Poverty Bay); Site 9 (along the Te Oneroa walkway shoreline); Sites 10, 11,12 and 13 (sites further away from the shoreline into the Poverty Bay); and Site 14 (on the Waikanae River). Other sites included in the QMRA and closest to the overflow discharge are Sites 6 (on the Waimata River), 7 (on the Taruheru River close to Oak Street) and 8 (on the Taruheru River close to Peel Street).

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

(c) Range (minimum, maximum and median) of pathogen concentrations in treated effluent: GDC conducted a limited 3-day microbiological analysis of the WWTP effluent grab samples (enumeration was conducted by Dnature NZ in 2019). However, the enumerated concentrations in the influent pathogen monitoring were lower than reported in previous NZ QMRA reports (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al 2017). Additionally, some pathogens were not detected at all in the monitoring exercise. These issues are not unique to the Gisborne WWTP influent pathogen monitoring data because of the sporadic nature of wastewater pathogen concentrations and the short duration of the sampling (Farkas et al 2018). Given these limitations, a precautionary approach was adopted and applied to the QMRA which relied on previously published ranges of pathogen concentrations.

(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[3] and provided to me; and dilution factors provided were used to conduct the

[3] Provided as Appendix J to the Application

QMRA. This approach is consistent with previous QMRAs undertaken in New Zealand[4].

(e) How much water an individual will ingest over a period of time during a particular recreational activity: Child[5] 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 2 of QMRA report) were consistent with previous QMRAs undertaken in New Zealand[6].

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

Dose Response Assessment

14. 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

15. 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 as individual illness risk (**IIR**) and classified into four groups in relation to the New Zealand recreational water quality guidelines (MfE/MoH 2003)[7].

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[4] (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al 2017)

[5] 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

[6] (Dada 2018a; 2018b; McBride 2016a,b, 2017; Stewart et al 2017, Hudson 2019)

[7] Table H1 the New Zealand recreational water quality guidelines (MfE/MoH 2003)

16. In the case of risk due to enteric illnesses as a result of ingestion of water affected by overflows, while swimming or via the consumption of raw shellfish, predicted IIRs for each site are classified[8] 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

17. In the case of acute febrile respiratory illness (**AFRI**[9]) 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;

(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;

[8] Consistent with previous QMRAs

[9] 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.

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

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

19. A precautionary and extremely conservative approach was adopted in the Gisborne overflow QMRA. This was achieved by accounting for extremely high influent virus concentrations that occur during on-going but undetected viral illness outbreaks in the community; assuming the wastewater overflow is not diluted by stormwater[10]; reporting children's illness risk as opposed to the generally lower adults' risk; including a dilution-only scenario that does not include solar ultraviolet-based inactivation of viruses; and applying a bioaccumulation factor to shellfish.

20. A key objective of the QMRA was to estimate health risks before and after improvements to stormwater and wastewater networks. That is, will the proposed future changes delivered through GDC's DrainWise Programme result in an improvement over existing conditions?

21. Three scenarios that reflect current and future overflow discharge conditions were therefore investigated in this QMRA: wastewater overflows during conditions of 2-year current, 10-year current and 10-year future annual recurrence interval (ARI) rainfalls[11]. The key QMRA results are presented in paragraphs 22 to 28 below.

Enteric Illness Risks (Swimming), 24 hours after the overflow

22. During the two scenarios of current overflow discharge (i.e. 2-Yr Current and 10-Yr Current ARI), overall predicted enteric illness risks among 100 individuals (children) who swim at 5 out of the 14 exposure sites were below the NOAEL (no observable adverse effect level, i.e. there is a probability of less than one case of gastroenteric illness in every 100 exposures). Low enteric illness risks were predicted to be associated with contact recreation at the 9 other exposure sites (i.e. Sites 1, 2, 4, 6, 7, 8, 9, 11 and 12), 24 hours after an overflow event, as a result of the current overflow discharge.

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[10] It should be noted that wastewater overflows in WWO events are inevitably diluted by stormwater. As stated in the Application at Section 2.4.1 (p19) information has been provided assuming a ratio of 4 parts stormwater to 1 part wastewater based on a pipe size of 5 times ADWF, which in itself is precautionary as modelling has shown the pipes to have a capacity of 6 times ADWF or more.

[11] No overflows are predicted for a future 2-year ARI overflow event, hence no QRMA was undertaken for this future scenario.

23. During the 10-Yr Future ARI scenarios (i.e. after implementation of GDC's DrainWise programme with concomitant stormwater inflow reduction and drainage improvements), overall predicted enteric illness risks among 100 children engaging in recreation at all 14 of the exposure sites were below the NOAEL.

24. It should also be noted that the assessment above predicts the risk of illness during/immediately following an overflow event. The aim of the DrainWise programme is to reduce the frequency of wet weather overflows from an average of 2.5 / year to less than 1 per 2 years. So not only does the health risk following an overflow event reduce, but the likelihood of an overflow occurring also decreases significantly.

Acute Febrile Respiratory Illness Risk (Inhalation), 24 hours after the overflow:

25. During the two current scenarios (2-Yr Current and 10-Yr Current ARI), overall predicted acute febrile respiratory illness risks among children who engage in secondary contact recreation (e.g. kayaking) at 4 out of the 14 exposure sites were below the NOAEL (no observable adverse effect level) 24 hours after the overflow. Low AFRI illness risks were, however, predicted to be associated with recreation at the other exposure sites (at Sites 1, 2, 4, 6, 7, 8, 9,10,11 and 12). The predicated illness risks will reduce even further 48 hours after overflow event, as the overflow becomes further diluted in the receiving environment.

26. During the 10-Yr Future ARI scenarios (i.e. after implementation of GDC's DrainWise programme with concomitant stormwater inflow reduction and drainage improvements), overall predicted respiratory illness risks among 100 children engaging in recreation at all 14 of the exposure sites were below the NOAEL. The predicated illness risks will reduce even further 48 hours after overflow event, as the overflow becomes further diluted in the receiving environment. Again, the frequency of overflow events is also reduced following the proposed improvements.

Enteric Illness Risk (Shellfish consumption), 24 hours after the overflow

27. Low to high risks are associated with consumption of raw shellfish harvested at all six of the exposure sites (i.e. Sites 1, 2, 3, 4, 5 and 9) 24 hours after the overflow, during the 2-Yr Current ARI and the 10-Yr Current ARI scenarios.

28. Following stormwater inflow reductions and drainage improvements (in the 10-Yr Future ARI scenario), overall predicted risks associated with raw shellfish consumption

predominantly ranged from low to moderate among 100 individuals who consume raw shellfish harvested from the receiving environment 24 hours after an overflow event.

29. From a health risk perspective, the results of this QMRA indicate that the future changes proposed in the Application (and to be delivered through GDC's DrainWise Programme) result in a significant improvement over existing conditions (i.e. health risks after proposed improvements are significantly lower than the status quo). These QMRA results agree with monitoring data collected after an overflow event, which show that the overflow plume is substantially diluted in the receiving environment within 24-48 hours after valve opening with concomitant reduction of indicator bacteria levels to near background levels (see Figure 1 below, which is Figure 24, p79 of the Application). Again, it is critical to note the very conservative nature of the health risk assessment that has been undertaken, as it assumes no dilution of the wastewater, when in fact during WWO events discharges are at a ratio of at least 4 parts (or higher[12]) stormwater to one part wastewater. Also above, the frequency of overflow events reduces significantly – so the likelihood of an overflow event occurring also reduces significantly.

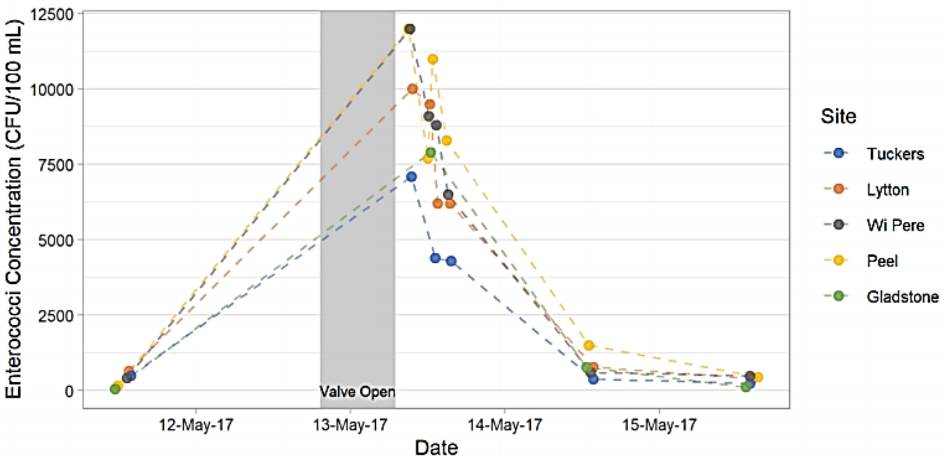

Figure 1 Enterococci concentrations – Taruheru River, 11-15 May 2017 (before, during and after a wastewater overflow event)[13]

30. In relation to the Map shown in Appendix 1 to my evidence, I understand from GDC that locations 1, 2, 3, 4, 5 and 9 are known sites where shellfish gathering may be carried out from time to time. I also understand that shellfish gathering at these sites is generally not regular, although sites 2 and 3 appear to be used more regularly. Palmer (2014) provided anecdotal evidence that shellfish is also gathered along the beach

[12] as per BECA wastewater modelling, which details pipe flows during wet weather
[13] Note this was provided as Figure 24, p79 of the Application.

between locations 1 and 9. I have been advised by GDC that shellfish gathering is generally not carried out at these locations during and after heavy rainfall, when overflow warning signs are up, the water is visibly discoloured, and shellfish gathering is difficult. Other locations can be used for collecting shellfish, but this is likely to be extremely rare.

RISK MITIGATION

31. It is important to note that the QMRA results presented here are for attributable risk; i.e., the increment in risk associated with the WW overflow 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[14] as a result of the WWO 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 for the WWO has provided a very conservative assessment, with a number of assumptions as set out in paragraph 19 above, including that there will be no dilution of the wastewater (when in reality the ratio for WWO is more likely between 4-6 parts stormwater to one part wastewater).

32. GDC has advised that it issues a series of notifications where overflows occur. This includes notification of the District Medical Officer of Health, erection of temporary warning signs at swimming and recreation sites, and communication with residents, relevant sporting clubs and the general public via Council's Facebook page, website, direct notification (e.g. emails) and other media channels. I consider such an approach is appropriate as a key way of managing health risks associated with overflows (both recreation and shellfish gathering) and I recommend that the Consent Holder should continue 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. I understand that Council's standard practice is for the health warning signs to be removed five days after the discharge valves are closed, but that period may be extended based on monitoring[15]. These efforts are highly effective with respect to mitigating risks associated with primary and secondary contact recreation.

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

[15] Application Section 3.3 at page 37

33. However, 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).

34. GDC has advised that bacterial water quality testing has in the past been carried out as soon as possible after the overflow valves have been opened and then daily for the next 5 days after an opening event. GDC has also advised that this has been carried out for over five years, and bacterial levels after overflow events are well understood. Consequently, bacterial testing is now carried out on day 5 only. Shellfish tissue virus levels are not currently monitored. To understand the persistence of viruses and to inform future monitoring, following an overflow event, I recommend that shellfish samples are collected from sites impacted by the discharge and enumerated for enteric viruses (enterovirus, norovirus) and *E.coli*. I understand that Council will be reviewing monitoring requirements as a condition of this consent, to have a more refined approach. Shellfish and viruses, among other new aspects, will be considered in that review.

35. I also understand that a permanent warning sign was in place at the Waikanae Stream mouth (located at approximately Site 4 on the map at Appendix 1; this appears to have been removed, not by GDC) and are on the Peel Street Bridge (located at approximately Site 8 on the map at Appendix 1) to discourage shellfish collection, due to a variety of potential contamination sources (i.e. not just wastewater overflows which are relatively infrequent occurrences). I also understand that Council is in a process of identifying other additional permanent signage locations, working together with Hauora Tairāwhiti, to mitigate health risks associated with shellfish gathering at sites vulnerable to contamination by wastewater, stormwater, closed landfills, and agricultural runoff, and so signage is required regardless of wastewater overflows. I understand that the Waikanae Stream sign will be reinstated as part of the above process, and existing signs on the Peel Street Bridge will be improved. These efforts are highly effective with respect to mitigating risks associated with shellfish gathering. Similarly, I would not expect, as a matter of course, members of the public to be gathering shellfish during an overflow event (and consuming it raw[16]) in light of the Council's notification procedures.

[16] 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/

S92 RESPONSES

36. The Reporting Officer sought further information from the Applicant in relation to several matters relating to the QMRA. These were addressed in Attachment F to the s92 response dated 29 January 2021; but are briefly summarised here.

The overflow wastewater sampling that produced the pathogen concentrations used in the QMRA report.

37. The overflow wastewater sampling (a three-day grab sampling) was completed by Dnature Diagnostics & Research Ltd NZ in 2019. Because of the sporadic nature of wastewater pathogen concentrations and the short duration of the sampling (3-days), it is possible that the data generated was not representative of the full range of wastewater pathogen concentrations. Due to the limited sampling information, the Gisborne QRMA applied pathogen concentrations typical of the ranges found in New Zealand. This is the approach that has been applied in a number of recent QMRAs (e.g., Hudson 2019 -NIWA Queenstown Stormwater QMRA, McBride 2017- Bell Island WWTP QMRA, Dada 2016, 2017). This is a conservative approach to ensure that risk is not under-represented.

Whether the virus dose-response curves were developed using cultured virus counts based on qPCR-based measures.

38. The dose-response curves applied were based on qPCR-based measures of viruses. It is important to note that the detection of viral genetic material does not necessarily equate to infectivity (even degraded DNA is detected by the PCR-based methods). From a public health perspective, as we have done in the Gisborne QMRA report[17], it is safer to assume a conservative stance during modelling, in which all the detected viral genetic materials are regarded as infectious. This approach may therefore over-estimate risk associated with the overflow discharge.

What proportion of the adenovirus concentration listed in the QMRA report was used was used to avoid over-estimation of risks.

39. We assumed that 10% of the overflow adenovirus concentrations listed in Table 3 (i.e., 10% of 2,000 – 30,000,000) were Adenovirus type 4. This is consistent with literature

[17] consistent with several previous QMRAs (e.g. McBride 2007, 2011; 2012; 2016a,b- Snells Beach and Warkworth WWTP QMRA, McBride 2017-Bell Island WWTP QMRA, Dada 2018a; 2018b, Dada and Gyawali, 2021)

published on the populations of adenovirus prototypes in raw wastewater (Fong et al. 2010) and also consistent with previous QMRAs; e.g. McBride (2017).

The potential risk of exposure to pathogens during dry weather when tidal and wind conditions can resuspend bottom sand/sediment and into the water column.

40. 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 can't 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).

41. The complexity behind sediment microbes is not peculiar to Gisborne. 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 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).*
>
> *"Although a review of the international literature showed that occurrence and survival of indicators and pathogens in the water column has been extensively investigated, the situation is less clear in sediments" (Weaver & Sinton 2009).".*

42. Regardless of whether or not sediment resuspension takes place, current health risk associated with resuspension will substantially decrease following the reduction in overflow frequency and volume, as proposed in the upgrades.

RESPONSE TO ISSUES RAISED IN SUBMISSIONS

43. The following issues relating to health impacts were raised in submissions lodged with Council:

    (a) Concerns regarding disposal near school site – Suzanne Orchard, Megan Rangiuia, Ruby Smith, Janet Crawford, Colleen and Beverley Dwyer, Ministry of Education; and

    (b) Need for better understanding of residual contaminants in sediment/shellfish – Rongowhakaata.

44. I respond to these issues below.

45. In relation to the school sites, this matter is addressed further in the evidence of Mr Kanz. I understand that the primary overflow location at this point (Seymour) is being removed and relocated, which requires both process changes and physical works which are currently being designed with a view to construction being implemented in the next (Council) financial year. Accordingly, this overflow point will be removed in the next year or so, which will remove the exposure risk. Again, these matters are set out in further detail in the evidence of Mr Kanz.

46. In relation to the seven school sites close to discharges (i.e. within 300m of a primary, secondary or tertiary overflow point), consideration has already been given in the QMRA to inhalation of aerosolized pathogens leading to AFRI, that may occur following during secondary contact exposure. This approach is consistent with previous NZ QMRAs undertaken in New Zealand when assessing health risks associated with secondary contact recreation, such as riverside jogging or kayaking. However, I note that the health risk has been determined as low given that the primary overflow point of concern (Seymour) is being removed by GDC, the overflows are relatively infrequent, and I consider that GDC's proposed notification procedures (including direct notification of schools in the vicinity) are sufficient to mitigate any remaining risk.

Submission by Rongowhakaata Iwi Trust (Rongowhakaata)

47. Rongowhakaata's submission states at paragraph 1:

    The application fails to adequately address the public health implications of the continuing discharge of untreated sewage to our urban waterways. This is evidenced by an apparent lack of direct engagement with river water users, absence of any *relevant epidemiological studies, and the recognised need for a better understanding of residual contaminants, including viruses, in the sediments and shellfish.*

48. I address these comments below and in subsequent sections (paragraphs 49-52).

49. Rongowhakaata's submission (that the QMRA does not provide an adequate assessment of public health implications of the continuous discharge *of untreated sewage to urban waterways)* seems to misconstrue (i) the nature of the discharge and (ii) the purpose of the overflow QMRA report.

50. First and foremost untreated sewage is not being continuously discharged into urban waterways. They are occasional events. GDC has advised that the frequency of occurrence of these events, as observed in the past 15 years, is an average of 2.5 times per year. Following the proposed upgrades, the Application provides for targets for future overflow events no more than once every 2 years, which is a fivefold reduction of overflow events frequency and corresponding reduction in volumes of overflow discharged. Reducing the frequency and volume of overflows is the best way to minimise risk.

51. Secondly, the objective of the health risk assessment differs considerably from what Rongowhakaata's submission suggests. As previously stated above (paragraph 20), a key objective of the QMRA was to estimate health risks associated with these overflow events before and after future improvements to stormwater and wastewater networks as delivered through GDC's DrainWise Programme. In other words, which scenario is associated with comparatively lower health risks (wastewater overflows during current conditions of 2-year, 10-year annual recurrence interval (ARI) rainfalls versus future 10-year ARI rainfalls).

52. It is also important to note that most of the overflow events occur during winter. From a microbial risk perspective, there are a couple of points to note. Firstly, this is advantageous in that urban waterways are less frequently used for recreation and kai gathering, resulting in lower health risks than would have been the case during dry weather conditions[18]. However, ultraviolet radiation-based inactivation of pathogens in the receiving environment is largely non-existent during winter, thus potentially

[18] During dry weather events, a small volume of overflow discharge during low flow periods and reduced dilution in receiving city rivers could make the water unsafe for recreation (i.e. elevated health risks). However, the likelihood of a significant volume of untreated wastewater entering Gisborne's waterways in dry weather is low, and GDC has advised that an overflow notification protocol is followed if sufficiently large overflows occur, including notifying potential water users.

extending their persistence in the environment. Although there is the possibility of enteric viruses bioaccumulating more efficiently in shellfish during winter (Maalouf, et al 2011, Araud et al 2016); these bioaccumulation considerations have already been accounted for in the Gisborne QMRA (through the application of a bioaccumulation multiplier factor). As such the results presented in the QMRA already address/reflect these bioaccumulations in shellfish during winter.

53. Rongowhakaata has suggested, in its submission, that an epidemiological study should be undertaken. In my opinion, such an approach is not necessary. In relation to potential health risks associated with contaminated water, experts typically ask the following questions :

(a) Are exposed individuals likely to get sick after ingesting or inhaling water or consuming raw shellfish harvested from the water (i.e. risk modelling as done in the QMRA)?; or

(b) Are people getting sick from exposure to the water (i.e. epidemiology)?

54. It is important to note that epidemiological studies are prohibitively costly and time-consuming to conduct (SCCWRP 2021). In addition to their costly nature, they require larger population sizes and tend to become overly complicated if varying scenarios are included, as described here: “many permutations of potential pathogens, sources of contamination and environmental influences which renders examination of all scenarios via epidemiological methods impossible” (Beaudequin 2016). Given these considerations, epidemiological studies often end up being limited in scope.

55. Also, the self-reported nature of the data collected in epidemiological studies tends to make epidemiological studies biased, thus making routine implementation impractical should findings from such studies be used to inform decision-making, without some form of bias correction. Some of these biases, which may be based on individual participants’ perceptions of risk, are published in the literature (further examples can be seen in the section dedicated to skin sores). For instance, according to Fleisher and Fleming (2010), *“swimmers might be more likely to report symptoms than non-swimmers because they suspected that swimming may have caused whatever symptoms they experienced…”*

56. Not surprisingly, Fleisher and Kay (2006) categorically stated that:

> *"risk perception bias can be strong enough to lead to spurious associations in the presence of self-reported symptoms and should be controlled for in future epidemiologic studies of recreational water-associated illnesses and other water-associated environmental exposures where the use of self-reported symptoms cannot be avoided".*

57. Despite the difference between QMRA and epidemiological approaches, QMRA incorporates epidemiological approaches. Beaudequin (2016) argued that:

> *".. the QMRA process is based upon the classic 'epidemiological triangle' comprising the pathogen, the human host and the environment in which exposure takes place. Following identification of the 'hazard' or pathogen of interest, the dose response and exposure assessment steps of QMRA can be envisioned in the epidemiological triangle as the pathogen-host interaction and the environment-host and environment-pathogen interactions, respectively".*

58. Also, a QMRA approach to assessing health risks performs better in the examination of several permutations of multiple scenarios, which may be impossible, cost-ineffective or biased when assessed using epidemiological methods. According to Beaudequin (2016);

> *"QMRA models are used to generate knowledge about the propagation of microbiological hazards along the risk pathway from source to exposure in complex real-world scenarios. The primary purpose of these models is to generate insight into the interdependence of variables (input and output) and to quantify the effect of mitigation alternatives (Greiner et al., 2013). The QMRA framework is more informative in the consideration of pathogenic risk because it can be used to predict relative risks for several alternate scenarios and to evaluate efficacy of management options (Soller, 2008). QMRA is useful where no epidemiological data exist, until new epidemiological studies are developed and/or where epidemiological studies may not be practical or appropriate (Soller, 2008).*

59. Given these considerations, a QMRA is therefore a practical alternative to epidemiology. According to US Geological Survey Laboratory for Infectious Disease and the Environment:

> *"Compared to epidemiology, QMRA provides an economical and practical alternative for estimating health risk and identifying influential risk factors".* USGS (n.d.).

60. These reasons explain why the QMRA, instead of an epidemiological approach, was used to assess risks in relation to the Gisborne WW overflow events. This approach is consistent with a number of New Zealand studies[19] that have assessed health risks associated with wastewater discharges and overflows. QMRA also proved to be an effective approach in a recent study that compared how modelled public health risk profiles could change under alternative sewer overflow management strategies during 12- and 24-month rainfall-runoff events (Kozak et al 2020), without the need for an epidemiological study. Beaudequin (2016) argued that:

> *"QMRA is used worldwide by government agencies to protect public health from harmful exposure to waterborne and foodborne pathogenic organisms and to inform policy and decision making regarding these exposures (WHO, 2008). The QMRA framework has been applied to evaluate and manage pathogen risks for various risk pathways in drinking, recycled and recreational waters, food and the use of biosolids (Soller, 2012)*."

61. Rongowhakaata's submission also touches on the recognised need for a better understanding of residual microbes, including viruses, in sediments and shellfish. While I acknowledge that some gaps in knowledge remain with respect to pathogens in sediments (as already stated in paragraphs 40-42 above), I consider that the health effects associated with shellfish gathering have been assessed.

62. In relation to residual microbes in shellfish, this has already been addressed in the QMRA by the incorporation of the shellfish bioaccumulation factor, consistent with a number of previous QMRAs undertaken in New Zealand[20]. Shellfish[21] are known to filter feed.

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[19] McBride 2007, 2011; 2012; 2014, 2016a,b- Snells Beach and Warkworth WWTP QMRA, McBride 2017-Bell Island WWTP QMRA, Hudson 2019; Dada 2018a; 2018b

[20] E.g. McBride 2007, 2011; 2012; 2014, 2016a,b- Snells Beach and Warkworth WWTP QMRA, McBride 2017-Bell Island WWTP QMRA, Hudson 2019; Dada 2018a; 2018b

[21] E.g. bivalve molluscs

Hence, they can take up pathogens directly from the water column and bioaccumulate these 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, and filtration activity (Grodzki et al 2014).

63. In the Gisborne overflow QMRA, bioaccumulation is represented by the additional multiplier effect[22] called the pathogen bioaccumulative factor (Mean = 49.9, Standard deviation = 20.93) applied in our model, and consistent with international literature and several previous NZ QMRAs (Bellou, Kokkinos, and Vantarakis 2013; Hanley 2015; Hassard et al. 2017, Dada 2018a; 2018b; Dada 2019; McBride 2007, 2011, 2012, 2016, Hudson 2019). Accordingly, I consider that such concerns have been addressed and assessed as part of the QMRA.

64. However, as I advise above, consideration should be given to assessing the persistence of viruses in shellfish following an overflow event.

CONCERNS ABOUT NON-ENTERIC OR NON-RESPIRATORY CONDITIONS

65. As is standard practice when assessing risks associated with wastewater discharges in New Zealand and worldwide, the Gisborne QMRA has focused wholly on gastroenteric and acute febrile respiratory illness risks. Recent studies (e.g. Fawtrell & Kay 2015) that have reviewed health impacts associated with recreational water use (including gastrointestinal illness, respiratory infections, eye infection, ear, nose, and throat complaints, and skin problems) have concluded that gastroenteric and acute febrile respiratory illness risks are the most common problems. This observation has also formed the rationale for the development of water quality criteria world-wide.

66. In New Zealand, the existing microbiological water quality guidelines assess health risks associated with contaminated water for two types of infection and illness:

(a) Gastrointestinal disease, acquired via ingestion during recreational water-contact, and consumption of raw shellfish flesh; and

[22] Used to multiply the virus concentrations.

(b) Respiratory ailments, via inhalation of aerosols formed e.g. when water-skiing, surfing, or through wind-induced dispersals affecting individuals that may be jogging, kayaking etc near waterbodies.

67. According to a recent study (McBride 2017):

> "*Other categories of diseases, especially ear, nose, throat and skin infections have generally not been included in QMRA studies to date, not least because while there is some evidence of associations between these ailments and microbial water quality (Charoenca & Fukioka 1994), dose-response models (WHO 2003, p. 55) have not been developed."*

68. Only recently did studies begin to publish on the development of dose-response models to these other categories of non-enteric or non-respiratory illnesses that are associable with contaminated water (e.g. Roser et al 2014, Esfahanian et al 2019, Dean & Mitchell 2020, Kusumawardhana et al 2021).

69. I am aware that there has recently been media reporting regarding concerns about whether WWO events are capable of causing non-enteric or non-respiratory infections among waterway users (such as skin infections caused by contact with the potentially polluted water). These matters are not explicitly raised in submissions (other than in passing in the submission of Josie McClutchie). However, I have addressed them below for completeness.

70. These concerns may be reflective of two scenarios:

(a) Self-reported biases, as have been commonly observed in studies that have investigated the association between exposure to recreational water and skin ailments. Some of these are captured below:

> *"…bathers who perceived that there was a health risk associated with bathing in marine waters reported significantly higher rates of skin ailments compared to bathers who did not recognize any health risk associated with bathing in marine waters" (Yau et al 2009)*
>
> *…bathers having pre-conceived notions of any health risk due to the exposure were 10.63 times more likely to report skin ailments relative to the unexposed (non-bathers), while bathers without any pre-conceived notion of risk were no more likely to report skin ailments relative to non-bathers* (Fleisher and Kay 2006).

> *"…there is the potential for participants in studies to have over-reported their incidence of skin ailments, thus theoretically causing results in those studies to be biased upwards" (Yau et al 2009)*

(b) On the other hand, these concerns relating to skin infections potentially linked to the overflow events may also be valid. Studies have shown that recreational waters with known point sources of faecal contamination (e.g. domestic sewage or storm-drain runoff) has been associated with an increased risk for transmission of infectious diseases including skin infections (Fleisher et al 1996, Haile 1999, Graciaa et al 2018). Out of an abundance of caution, therefore, a risk assessment was conducted in relation to a pathogen (Staphylococcus aureus) that has been related to skin infections following exposure to polluted recreational water.

RISK ASSESSMENT FOR *S.aureus* SKIN INFECTIONS

71. *Staphylococcus* species colonize the skin and are the most common etiologic agents associated with saltwater and freshwater skin and soft tissue infections (Leonard et al 2018, Goldstein et al 2012*).* Details of the additional risk assessment methodology for *S.aureus* skin infections are presented in the appendix. Results are presented below.

72. During the two scenarios of current overflow discharge (i.e. 2-Yr Current and 10-Yr Current ARI), for a single site where worst case dilution occurs, as predicted individual skin infection risks were 0.0005 and 0.0007%, respectively. The implication of this is that, on the average, among 100,000 individuals who use the receiving water, there is a probability that less than 1 individual will develop skin infections. This infection probability is extremely low.

73. During the 10-Yr Future ARI scenarios (i.e. after implementation of GDC's Drainwise programme with concomitant stormwater inflow reduction and drainage improvements), predicted individual skin infection risks marginally reduced to 0.00001%.

74. The extremely low probability of *S.aureus* skin infection as a result of the overflow discharge across scenarios is not surprising. Previous risk assessment studies in New Zealand (for instance, Stott and Hudson, 2019) have reported that *S. aureus* has a relatively low infectivity and that very high concentrations of cells would be required to cause an infection.

PROPOSED CONSENT CONDITIONS INCLUDING MONITORING PLANS

75. The suggested recommendations below (paragraphs 76- 77) can potentially contribute to overall efforts aimed at protecting and/or restoring waterways in the Gisborne district.

76. I support the comprehensive notification protocols that GDC undertakes as an effective way of managing risk exposure. However, to further manage health risks, particularly in relation to raw shellfish consumption, I recommend that council monitors the sites where shellfish collection frequently occurs e.g. Kaiti beach for water and shellfish tissues FIB and virus concentrations over several weeks after at least four overflow events. The monitoring data when compared with baseline data will help inform any amendments that may be required to monitoring and/or notification conditions, in discussion with Hauora Tairāwhiti.

77. Consistent with the approach used by previous NZ QMRAs for wastewater discharge, the predicted risks reported in the Gisborne QMRA are only incremental risks that occur as a result of an overflow event (i.e. attributable risks). However, it is important to note that the baseline water quality of the city rivers is subject to the influence of land use in the upstream catchments, as well as from other urban discharges. Even without the overflow discharge events, background microbial water quality will continue to be impacted by upstream land use activities and discharges from the urban area. The QMRA does not capture risks present in baseline conditions such as non-event days/periods. For instance, while the QMRA results indicate that attributable risks associated with contact recreation in the future overflow discharge scenario are below the "no observable adverse effects level", risks present in the baseline conditions of the river may already be at high levels due to other discharges from the urban area.

78. I note that Council is already in a process of applying a catchment-wide approach that considers contamination by wastewater, stormwater, closed landfills, and agricultural runoff.

Response to issues identified in the s42A Officer's Report

79. I agree with the s42A Officer's Report (Section 9.26) that public health effects associated with the overflow "can be mitigated and managed to an appropriate degree" and that GDC "has already developed methods to manage the effects from wet weather discharges which are both appropriate and effective".

80. In relation to dry weather overflow events, as noted in the s42A Officer's Report (Section 9.27) "in terms of dry weather discharges, it is difficult to quantify the nature and scale of any environmental effects as these will be determined by the location and nature of the specific event". However, it is important to note that these discharges are also infrequent, temporary in nature, typically smaller volumes of discharges. I also understand that the dry weather discharges do not always reach waterways.

81. To prevent health risks associated with dry weather events, I consider it is appropriate for GDC to take a proactive approach to sewage infrastructure maintenance and repairs of mechanical breakdowns in a way that reduces, as is practically possible, the chances of dry weather overflows occurring. As outlined in the evidence of Mr West, GDC undertakes a multi-faceted approach to managing DWO which includes a proactive maintenance regimes, systems controls and duplications, a comprehensive public education campaign, and prompt response and clean-up protocols (along with notification and monitoring responses as I have described above).

82. GDC has advised that the fourteen QMRA exposure sites used for assessment of health risks associated with recreation and shellfish gathering were quite extensive. Nonetheless, I agree with the recommendation of KIWA Engagement Group Report as stated in Section 9.35 of the s42A Officer's Report, that GDC will need to work more with local groups to identify further at-risk sites and locations relevant to recreation, shellfish gathering, and other Māori resource-use practices. As already stated in paragraph 35 of this evidence, Council already has projects and processes underway in addressing other contaminant sources (i.e. not related to this Application) including wastewater, stormwater, closed landfills, and agricultural runoff, which I would support as part of an integrated approach to managing risks.

83. Paragraph 83 of the Technical Report supporting the s42A Report (Appendix 4) (**Technical Review**) raised issues related to non-enteric and non-respiratory infections in the media which may be due to "contaminants from multiple sources, making it difficult to attribute the skin conditions to any one contaminant source". I agree with the Technical Review on this point. I also recognize, in line with international literature, the possible bias around reporting of skin conditions following exposure to recreational water as already highlighted in paragraphs 69 and 70 of this evidence. For the avoidance of doubt, I have conducted additional risk assessment modelling to focus on attributable risks due to the overflow discharge alone using worst case dilutions (paragraphs 71-74) and conclude that the probability of developing skin infections as a

result of the overflow discharge is very low and will further reduce as overflow frequency is reduced over time.

84. Paragraph 93 of the Technical Report recommends pathogen testing of background microbial indicator and pathogen concentrations in tuatua, mussels and other bivalve shellfish at popular estuarine and coastal shellfish gathering locations in the vicinity of the Tūranganui River mouth. I agree with this position, as have been previously iterated in paragraphs 34,76 and 77 of this evidence.

SUMMARY AND CONCLUSIONS

85. The QMRA approach has been recognised by the Technical Review as being conservative (i.e. more protective) in its approach. The elements of conservatism are noted in my evidence, including the adoption of 'no dilution' when in fact WWO are diluted at a rate of at least 4 parts stormwater: 1 part wastewater.

86. The QMRA results predict that the proposed future changes delivered through GDC's DrainWise Programme will result in a significant improvement over existing conditions (based on all responses considered, i.e. reduced health risks in relation to gastroenteric, acute febrile respiratory illness and skin infections, see Table 1).

87. Low to moderate health risks following consumption of raw shellfish harvested from the receiving environment 24 hours after an overflow event are still predicted in relation to overflow discharges during future improved conditions. However, this will improve as Council is currently considering permanent signages at shellfish gathering locations to discourage shellfish collection. I consider such signage would also assist in managing health risks associated with other inputs unrelated to this Application, including closed landfills, urban and agricultural runoff.

88. In relation to DWO, I note that Council has a multi-faceted approach to overflow prevention, management and response, which I support, to address health risks associated with those wastewater overflows (which are relatively infrequent occurrences). Consent conditions should ensure these discharges are managed to the extent possible, with appropriate monitoring and reporting if they do occur, along with notification protocols and procedures which will manage any potential health risks in an appropriate manner.

Table 1 Comparison of risks across scenarios

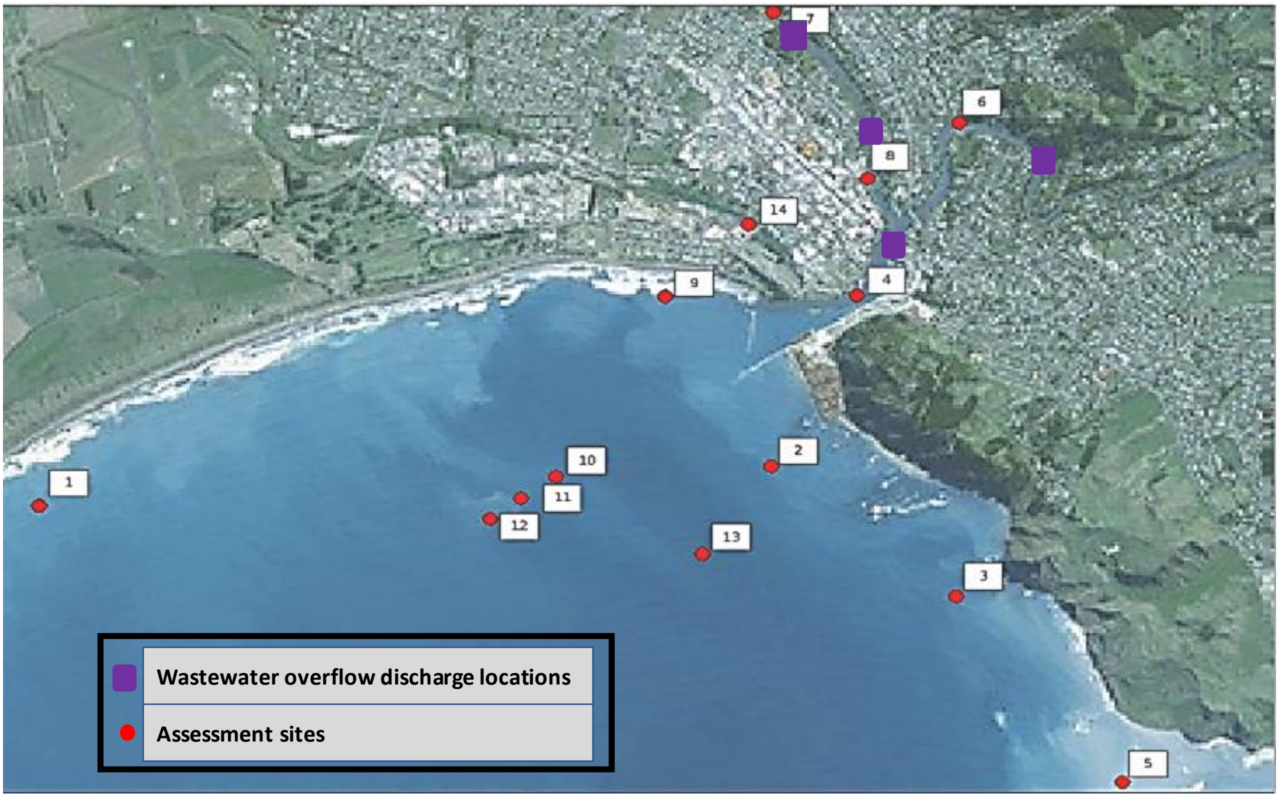
		Existing overflow discharge		**Future overflow discharge (after improvements)**	
Response	**Reference Pathogen**	**2-yr Current ARI**	**10-yr Current ARI**	**10-yr Future ARI**	**Change in health risks**
Gastroenteric illness (ingestion while swimming)	Enterovirus, norovirus	Low risks	Low risks	Risks<NOAEL	Significant reduction after proposed improvements
Acute febrile respiratory illness (inhalation during short exposure e.g. riverside walking)	Adenovirus	Low risks	Low risks	Risks<NOAEL	Significant reduction after proposed improvements
Gastroenteric illness (raw shellfish consumption)	Enterovirus, norovirus	Low/Moderate/ High risks	Low/Moderate/ High risks	Low/Moderate	Significant reduction after proposed improvements
Skin infection (after full body immersion)*	*S.aureus*	Low risks**	Low risks**	Risks<NOAEL*	Significant reduction after proposed improvements

* note that individual illness risks classification does not exist for skin infections. The classification for ingestion was cautiously applied here, i.e. NOAEL (predicted risk profile <1%), low risk (1-5%), moderate illness risk (5-10%) and high illness risk (>10%)
** IIR lower than 2-yr Current ARI current but still within the same risk category

Dr Christopher Ayokunle Dada

25 June 2021

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



Sites 6, 7, 8 and 14 are estuarine sites while all other sites are marine. Sites modelled: Site 1 (farthest horizontal distance to discharge along the Centennial Marine Drive shoreline); Sites 2, 3 and 5 (along the Kaiti Beach Road shoreline); Site 4 (close to Wainui Road and the outlet of the discharge into the Poverty Bay); Site 9 (along the Te Oneroa walkway shoreline); Sites 10, 11, 12 and 13 (sites further away from the shoreline into the Poverty Bay); and Site 14 (on the Waikanae River). Other sites included in the QMRA and closest to the overflow discharge are Sites 6 (on the Waimata River), 7 (on the Taruheru River close to Oak Street) and 8 (on the Taruheru River close to Peel Street). While primary and secondary contact recreation may occur at Sites 1-14, shellfish gathering is known to occur at sites 1, 2, 3, 4, 5 and 9 (other areas may be used for shellfish gathering, but this is considered rare and will be discouraged by permanent signages that GDC will be erecting)

APPENDIX 2: NON-ENTERIC OR NON-RESPIRATORY CONDITIONS

RISK ASSESSMENT FOR *S.aureus* SKIN INFECTIONS

89. While there were no *S.aureus* monitoring data for the overflow discharge, I have applied published literature ranges of concentrations recovered from several wastewater treatment plant influent samplings for the preliminary risk assessment. *S. aureus* ranged from 10^3 to 10^5 cfu/100mL (Lopez et al 2019).

90. A worst-case scenario of minimum dilutions (as informed by the MetOcean hydrodynamic modelling) was used to provide a conservative estimate of 'worst case' pathogen concentration (a precautionary approach). Another conservative approach was to exclude UV-based pathogen inactivation or die-off in the environment. It is important to note that I did not consider any background pathogen concentrations (i.e. pathogens already in the river without the discharge) but instead considered incremental risks associated with the concentration of pathogens in the overflow discharge alone (i.e. attributable risks).

91. Generally a major factor influencing the adsorption of pathogens to the skin is the concentration of pathogens in the water and the thickness of water on the skin after the exposure (Pitol, et al 2017, 2020). To determine the pathogen dose a swimmer is exposed to, the equation below was applied, as adapted from published literature (Kusumawardhana et al 2021).

$$d = \frac{C}{worst\ case\ dilution} * (10^{-3.38} + h) * BSA \ldots\ldots \text{eqn (1)}$$

Where d = pathogen dose (CFU), C = concentration of pathogens in water (CFU/mL), h = thickness of water on skin after showering (cm) and BSA = Body surface area (cm^2), estimated by the equation (Yu et al 2010):

$$BSA = 71.3989 \times H^{0.7437} \times W^{0.4040} \ldots\ldots \text{eqn(2)}$$

Where H and W are height and weight, respectively.

92. An exponential model (Kusumawardhana et al 2021, Esfahanian et al 2019) was used to predict the probability of swimmers developing skin infection following exposure to *S.aureus* in the receiving water environment, 24hr after the overflow discharge. The model is given as

$$Prob_{skin\ infection} = 1 - e^{-k.d} \text{..........eqn (3)}$$

Where $Prob_{skin\ infection}$ = probability of developing skin infection, k = probability of the pathogen surviving and reaching the host, d = dose (CFU) determined from the equation(1) above. Risk of infection per discharge overflow scenario was calculated using 10,000 iterations of Monte Carlo simulations. Probability of developing infection was outputted as predicted individual skin infection risks (expressed in %).

93. Other assumptions in the risk assessment are captured in Table 2.

Table 2 Assumptions used in the assessment of skin infections risk associated with the Gisborne overflow discharge

Variables/dose response models	**Values**	**Reference**
Height (cm)	Uniform distribution (158,176)	Height of adults in New Zealand (figure.nz)
Weight (kg)	Uniform distribution (62,105)	Weight of adults in New Zealand (figure.nz)
Worst case dilution Current 2-yr ARI	6,287:1	MetOcean dilution model
Worst case dilution Current 10-yr ARI	3,170:1	MetOcean dilution model
Worst case dilution Future 10-yr ARI	7,930:1	MetOcean dilution model
Thickness of water remaining on skin after swimming (cm)	0.1	Adapted from Kusumawardhana et al 2021
Staphylococcus aureus (dermal contact route) exponential model	k=8.5 × 10^{-8}	Esfahanian et al 2019
Pathogen concentration cfu/100mL	*S. aureus:* 10^3 to 10^5 cfu/100mL (hockey stick distribution, as per previous NZ QMRAs)	Lopez et al (2019)

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