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Semi-quantitative microbial human health risk assessment of Kohukohu WWTP discharge in the Hokianga Harbour

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Contents

Executive Summary

As part of the process of renewing the resource consents for the Kohukohu Wastewater Treatment Plant (WWTP) marine shoreline discharge into Hokianga Harbour, a microbial human health risk assessment is required to address the enteric illness risks related to contact recreation and consumption of harvested shellfish.

As such, Far North District Council (FNDC) has contracted Streamlined Environmental Ltd (SEL) to provide a semi-quantitative microbial human health risk assessment for the current discharge of treated wastewater from Kohukohu WWTP to the Hokianga Harbour.

The study 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.
- Relies on the dilution factors generated by a three-dimensional hydrodynamic model, which predicts the fate of the wastewater analyte in the environment (in terms of dilution only) following discharge of treated wastewater from the Kohukohu WWTP.
- Assesses the impact of the wastewater discharge in terms of elevation of enterococci and FC concentrations in the receiving environment, by specifically not including and including background concentrations, respectively.
- Assesses whether this increase in FIB will cause the receiving environment water to breach existing guidelines for contact recreation or shellfish-gathering.

In consultation between SEL and staff at FNDC, 12 key sites were identified in the Hokianga Harbour for recreational water contact and harvesting of shellfish. These sites could be potentially impacted because of wastewater discharge (see Figure ES1; sites 1-12).

We assessed recreational health risk and shellfish harvesting health risk based on the currently consented limits and on worse case scenarios (95th percentile of historic data), under El Niño and La Niña conditions.

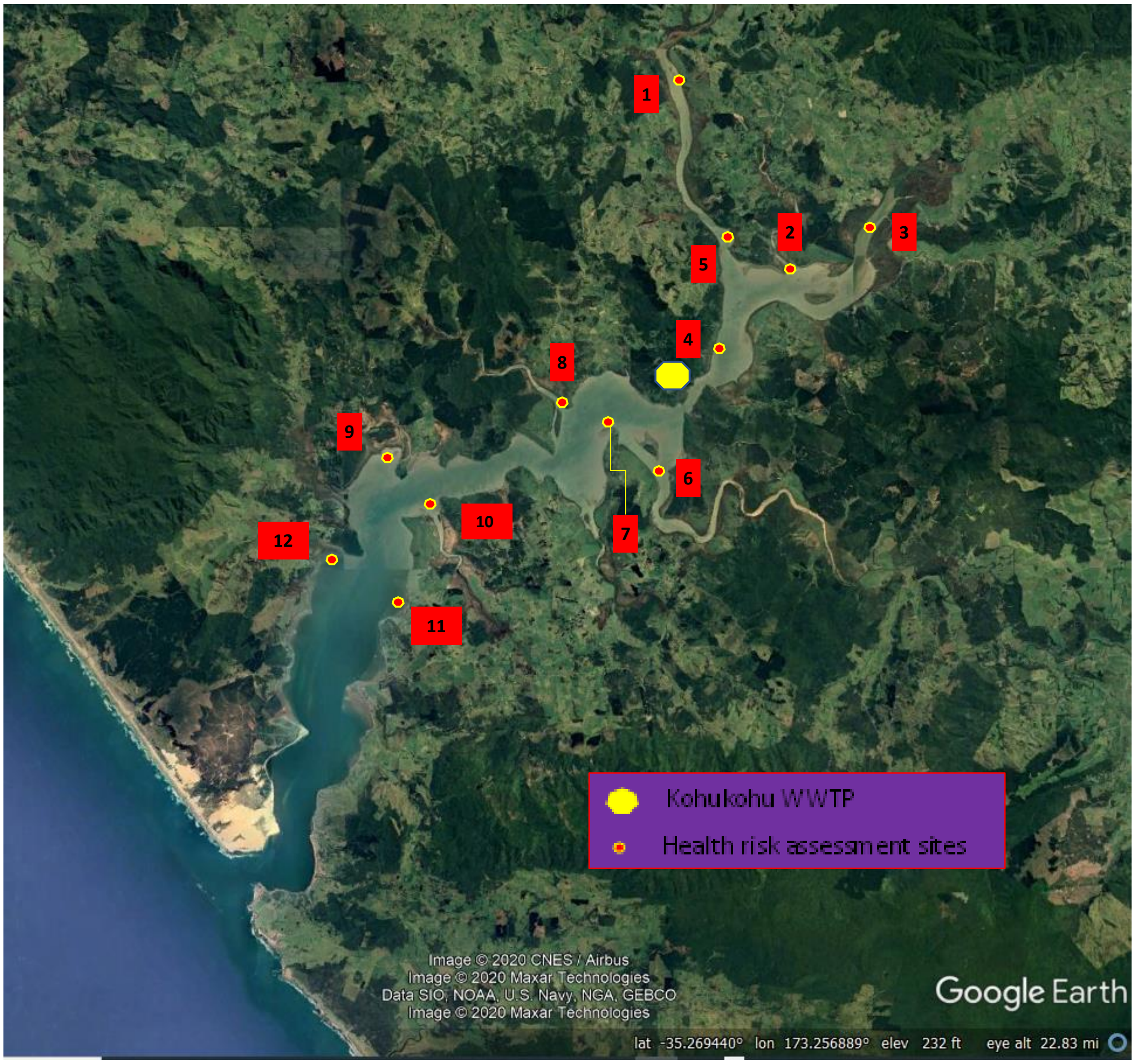

Figure ES1. Location of the 12 selected exposure sites in the Hokianga Harbour.

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 <u>does not negatively impact recreational water quality.</u> Based on dilutions occurring in the Hokianga Harbour, increases in faecal coliform in the receiving water due to the discharge from Kohukohu WWTP – even during the worst-case scenario – is +1 CFU/100mL. Additionally, enterococci concentrations at all 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.

Shellfish harvesting health risk

The quality of shellfish at the Hokianga sites currently does not meet the New Zealand Food Safety Authority (NZFSA) 2006 guidelines. As stated above, based on the worst-case scenario of Kohukohu WWTP discharge the maximum change in faecal coliform in the receiving water is + 1 CFU/100mL. Given this negligible change in water quality, the discharge is not expected to significantly affect shellfish quality.

1. Introduction

As part of the process of renewing the resource consents for the Kohukohu Wastewater Treatment Plant (WWTP) marine shoreline discharge into Hokianga Harbour, a microbial human health risk assessment is required to address the enteric illness risks related to contact recreation and consumption of harvested shellfish.

As such, Far North District Council (FNDC) has contracted Streamlined Environmental Ltd (SEL) to provide a semi-quantitative microbial human health risk assessment for the discharge of treated wastewater from Kohukohu WWTP to the Hokianga Harbour.

This report is presented into topical sections. Section 2 presents a discussion on the microbial characteristics of the Kohukohu WWTP discharge water in relation to existing resource consent limits, based on historical and current monitoring data. Section 3 discusses the microbial characteristics of the receiving environment in relation to existing New Zealand guidelines as stipulated in the Ministry of Health (MoH) 2003 microbiological water quality guidelines for marine and freshwater recreational areas (MfE/MoH, 2003). Section 4 presents a summary of the health risk assessment methodology, scenarios assessed and results. Section 5 presents conclusions, while Section 6 presents limitations of the study and recommendations for further studies and monitoring.

2. Characteristics of the Kohukohu WWTP discharge water

2.1 Discharge volumes of Kohukohu WWTP effluent

Analysis of Kohukohu WWTP flow monitoring data (2011-2019), provided by FNDC, indicates that:

- Effluent flow[1] ranged from 0.01 m^3/day to 610 m^3/day, with an overall median of 27 m^3/day (Table 1).
- For the majority (99%) of the time, when rainfall is below 50 mm, the effluent flow rate was below 154 m^3/day (Table 1).
- During conditions of significant rainfall exceeding 50 mm (Table 1), effluent flow rate increases by more than 5-fold above median flow rate. The cause of the increased flows is infiltration into the wastewater reticulation network, which is typical for most wastewater networks.
- The highest historical flow rates of 603 m^3/day and 610 m^3/day were recorded in summer 2011 when either daily rainfall or 24-hr antecedent rainfall exceeded 150 mm (Table 1).
- Aside from the significant rainfall events in the summer of 2011, in other years the maximum effluent flow rate recorded was 228 m^3/day.
- Effluent flow was generally lower during summer than during other seasons. For instance, during summer, 50% of the time, effluent flow rate did not exceed 13 m^3/day (compared to 27 m^3/day compared with annual flow rates, see Table 2).

[1] Kohukohu WWTP Flow - constructed wetland discharge (CWL) Out.

Table 1. Percentile distributions of annual Kohukohu WWTP influent and effluent flow rate, as well as 24-hr antecedent rainfall.

Statistic	Kohukohu WWTP Flow - Plant In [m^3/day]	Kohukohu WWTP Flow - CWL Out [m^3/day]	Rainfall - Plant [mm/day]	Antecedent 24-hr rain [mm/day]	Antecedent 48-hr rain [mm/day]	Antecedent 72-hr rain [mm/day]
Minimum	0.00	0.01	0.00	0.00	0.00	0.00
10th Percentile	12	3.0	0.00	0.00	0.00	0.00
20th Percentile	16	9.0	0.00	0.00	0.00	0.00
30th Percentile	18	15	0.00	0.00	0.00	0.00
40th Percentile	20	21	0.2	0.2	0.2	0.2
50th Percentile	23	27	0.4	0.6	0.4	0.4
60th Percentile	27	34	1.6	1.8	1.6	1.6
70th Percentile	32	44	4.0	4.0	3.8	3.8
80th Percentile	39	58	7.6	7.6	7.6	7.4
90th Percentile	53	87	15	15	15	15
95th Percentile	72	109	23	23	23	23
99th Percentile	128	154	49	49	49	49
Maximum	326	610	172	172	172	172

Table 2. Comparison of percentile distributions of summer and annual Kohukohu WWTP effluent flow rate.

Statistic	Kohukohu WWTP effluent flow [m^3/day]	
	Annual	**Summer**
Minimum	0.01	0.01
10th Percentile	3.0	1.0
20th Percentile	9.0	3.0
30th Percentile	15	5.5
40th Percentile	21	9
50th Percentile	27	13
60th Percentile	34	17
70th Percentile	44	23
80th Percentile	58	34
90th Percentile	87	57
95th Percentile	109	90
99th Percentile	154	132
Maximum	610	610

2.2 Analysis of wastewater quality data

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 (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 were below 900 CFU/100mL (Table 3).

Table 3. Descriptive statistics: Kohukohu constructed wetland discharge (CWL) water monthly and 5-month running median FC concentrations.

Statistic	FC, monthly [CFU/100 mL]	FC, 5-month running median [CFU/100 mL]
Minimum	27	100
10th Percentile	100	200
20th Percentile	200	400
30th Percentile	300	400
40th Percentile	475	582
50th Percentile	900	800
60th Percentile	1,800	1,800
70th Percentile	2,520	2,190
80th Percentile	5,000	2,360
90th Percentile	13,200	4,590
95th Percentile	24,400	7,663
99th Percentile	56,400	10,000
Maximum	114,000	10,000

2.3 FC comparison with existing consent condition limits

Condition 5 of the current resource consent (Consent No. CON20010383901) stipulates that:

- The median concentration of faecal coliforms, based on the five most recent samples from the Northland Regional Council (NRC) Sampling Site 323 should not exceed 5,000 per 100mL, or;
- The concentration of faecal coliforms in any one sample collected from the NRC Sampling site 323 should not exceed 15,000 per 100 mL.

Seven (7) of the 86 samples collected between 2010 and 2020 exceeded the consent monthly limit (~92% compliance level), while five (5) samples exceeded the consent five-monthly rolling median limit (~94% compliance level) (Figure 1).

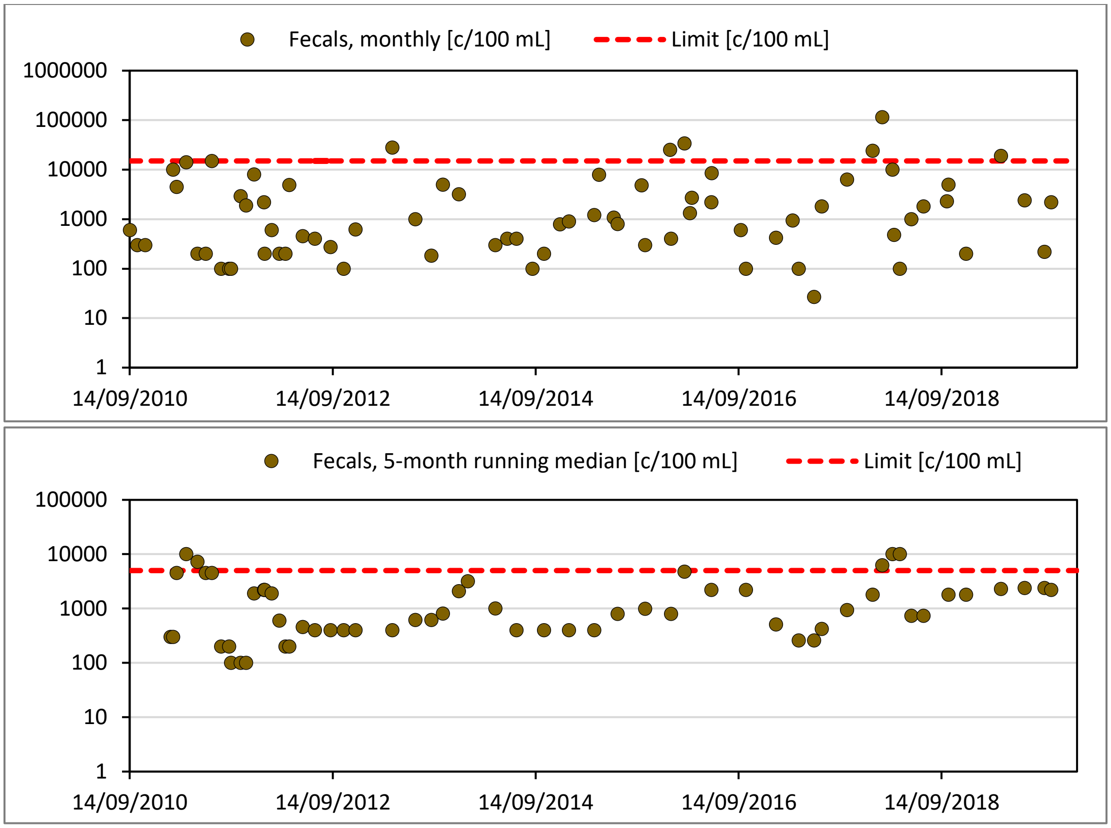

Figure 1. Compliance based on Kohukohu WWTP discharge water (2011-2019). Monthly FC concentrations (top), five-month rolling median FC concentrations (bottom).

The frequency of non-compliance with respect to the consent monthly limit appears to have slightly increased over the last decade (Figure 2). However, compliance with respect to consent five-month rolling median limit has been 100% for 8 years, with the notable exception of samples collected in the summer of 2011 (85% compliant) and 2018 (73% compliant) (Figure 2).

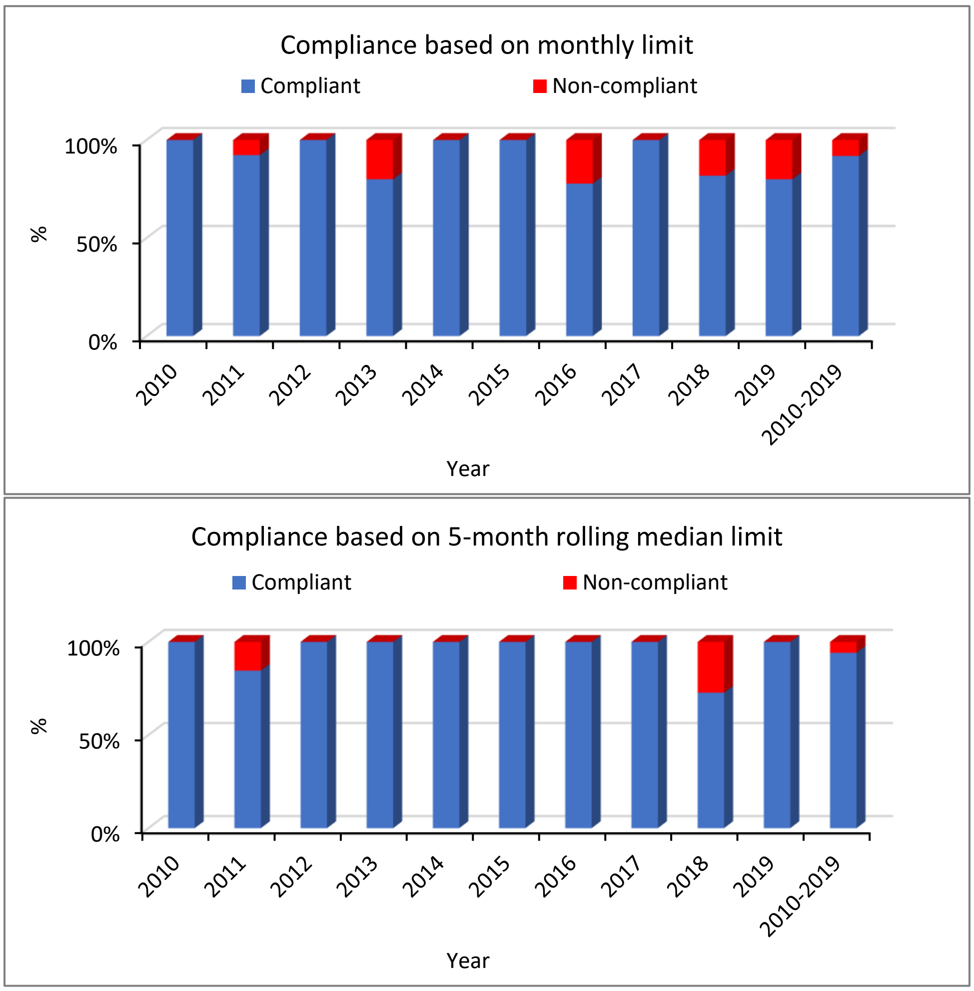

Figure 2. Annual proportion of single sample FC exceeding the 15,000 CFU/100mL monthly limit (top) and 5,000 CFU/100mL five-month rolling median (bottom) for Kohukohu WWTP discharge water (2011-2019).

3. Microbial characteristics of the aquatic receiving environment

Covering approximately 15,414 ha, the Hokianga Harbour is the fourth largest harbour in New Zealand (NRC, 2013). The harbour entrance has been classified as having high salinity, oceanic water, strong currents, high water clarity and short water residence times (NRC, 2013). Previous studies have shown that two major water quality issues exist in the harbour; excessive siltation and water discolouration from accelerated erosion and bacterial pollution from sewage disposal and pastoral run-off (NRC, 2013).

In terms of the Kohukohu WWTP discharge and from a compliance perspective, important receiving environment sites are described below. The receiving environment immediately downstream of the discharge has Site 231 as a compliance site (Figure 3). The outer receiving environment has other locations in the tidally influenced Hokianga Harbour that could potentially be affected by discharge from this WWTP. Microbial characteristics of the immediate and outer receiving environment, in relation to existing guidelines and consent conditions are presented in Sections 3.1 and 3.2, respectively.

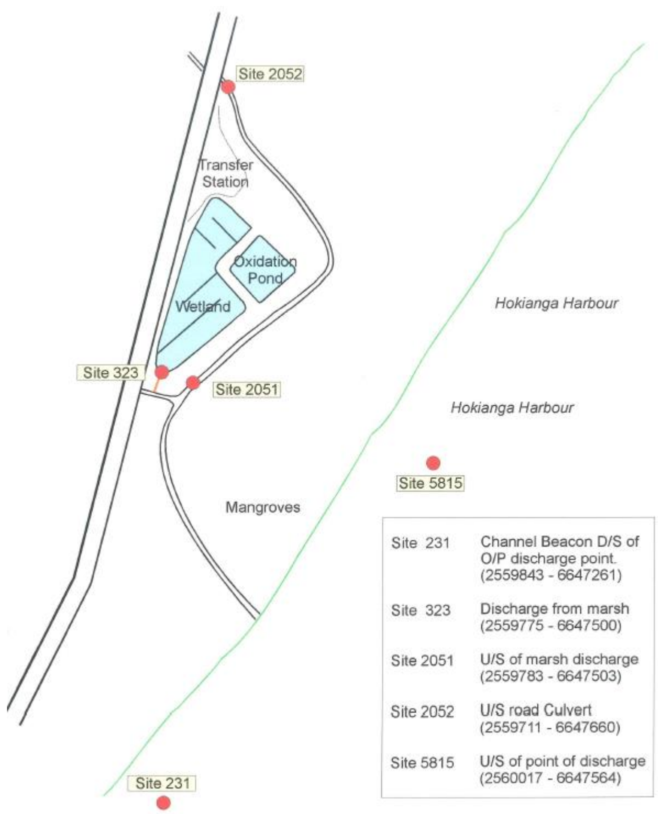

Figure 3. Compliance monitoring points identified in the existing consent.

3.1 Immediate receiving environment (Site 231)

Notwithstanding the quality of the discharge stipulated in Condition 5, Condition 7 of the existing resource consent makes additional provision for receiving water quality monitoring at Site 231 in the Hokianga Harbour. According to the consent document, based on no fewer than 10 (ten) samples taken over any 30-day period:

- The median concentrations of the FC bacteria in the water at Site 231 shall not exceed 14 per 100mL, and;
- The 90th percentile concentration shall not exceed 43 per 100 millilitres.

There has been no historic monitoring at this site.

3.2 Outer receiving environment

Aside from Site 231, a number of other sites which are downstream of the discharge could potentially be impacted by the treated effluent, hence the need to consider FIB concentrations at sites other than Site 231. However, it is important to note that, depending on tidal conditions, these outer sites can also be affected by discharges from other WWTPs discharging into the Hokianga Harbour, such as Kaikohe, Opononi and Rawene WWTPs.

3.2.1 Recreational water quality

As part of the Northland region's coastal monitoring exercise, NRC has conducted short-term monitoring of water quality at several sites within the vicinity of the discharge in the Hokianga Harbour, namely:

- A monitoring programme at 16 sites in the Hokianga Harbour between June 2009 and June 2010 (Figure 4).[2]
- Monitoring of 11 sites in the Hokianga Harbour was undertaken in 2013 to assess water quality (Figure 5) (NRC, 2013).

Samples were analysed monthly for FIB (*E. coli*, enterococci and faecal coliforms) and concentrations compared to available MfE/MoH guidelines, which propose a three-tier management framework based on enterococci indicator values, i.e. surveillance (green), alert (amber) and action (red) modes (Table 4). While the surveillance mode involves routine (e.g. weekly) sampling of bacteriological levels, the alert mode requires investigation of the causes of the elevated levels and increased sampling to enable the

[2] https://www.nrc.govt.nz/resource-library-archive/environmental-monitoring-archive2/state-of-the-environment-report-archive/2011/state-of-the-environment-monitoring/our-coast2/coastal-water-quality/#Harbour

risks to bathers to be more accurately assessed. The action mode requires the local authority and health authorities to warn the public that the beach is considered unsuitable for recreation (Table 4).

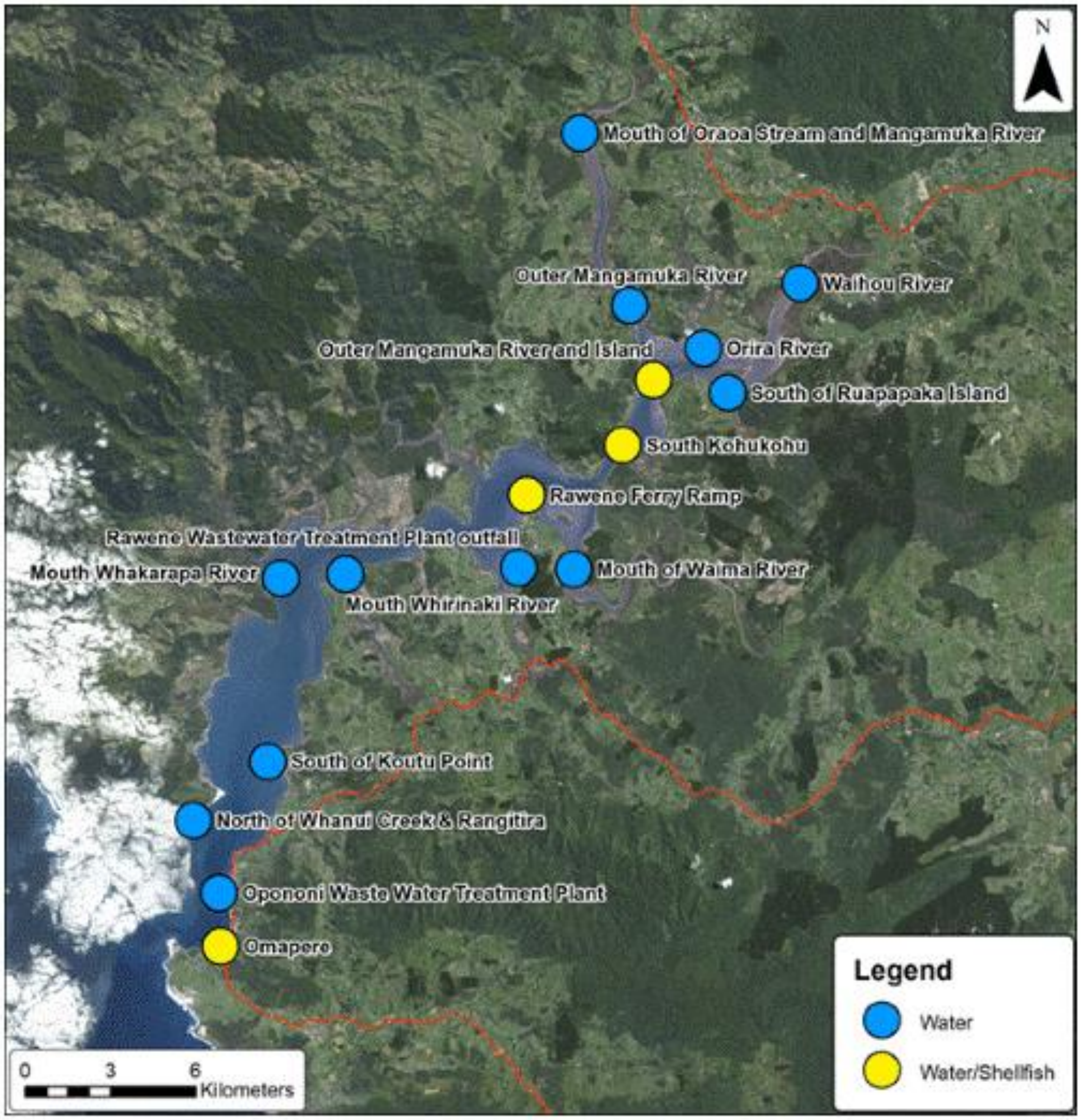

Figure 4. NRC Hokianga Harbour water quality monitoring sites (June 2009-2010).[2]

Figure 5. NRC Hokianga Harbour water quality monitoring sites (2013 monitoring (NRC, 2013)).

Table 4. Surveillance, alert and action levels for marine waters (MfE/MoH, 2003).

Microbiological Assessment Category (MAC)	Threshold	Implication
Acceptable/Green (surveillance) Mode	No single sample greater than 140 enterococci/100 mL	Continue routine (e.g. weekly) monitoring.
Alert/Amber Mode	Single sample greater than 140 enterococci/100 mL.	Increase sampling to daily (initial samples will be used to confirm if a problem exists). Undertake a sanitary survey and identify sources of contamination.
Action/Red Mode	Two consecutive single samples (resample within 24 hours of receiving the first sample results, or as soon as is practicable) greater than 280 enterococci/100 mL.	Increase sampling to daily (initial samples will be used to confirm if a problem exists). Undertake a sanitary survey and identify sources of contamination. Erect warning signs and inform public through the media that a public health problem exists.

Results obtained in the 2009-2010 monitoring showed that the levels of FIB were usually within the MfE/MoH guidelines for swimming/contact recreation (Figure 6).[2]

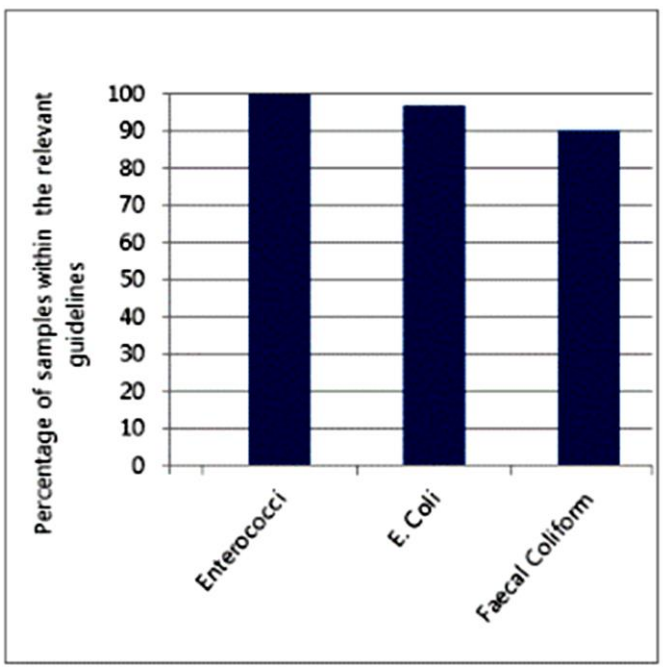

Figure 6. Hokianga Harbour water quality compliance results (2009-2010[2]).

Results obtained in the 2013 monitoring also showed that the levels of FIB were usually within the MfE guidelines for swimming/contact recreation (Figure 7). According to NRC, the total range was from 5 to 41 MPN/100mL for enterococci and 1 to 42 CFU/100mL for faecal coliforms. For eight of eleven sites enterococci levels were below detection limits (5 MPN/100mL) and the remaining sites were within guideline values. The highest reading was 41 MPN/100mL at the upper Mangamuka at Tetekuha (NRC, 2013).

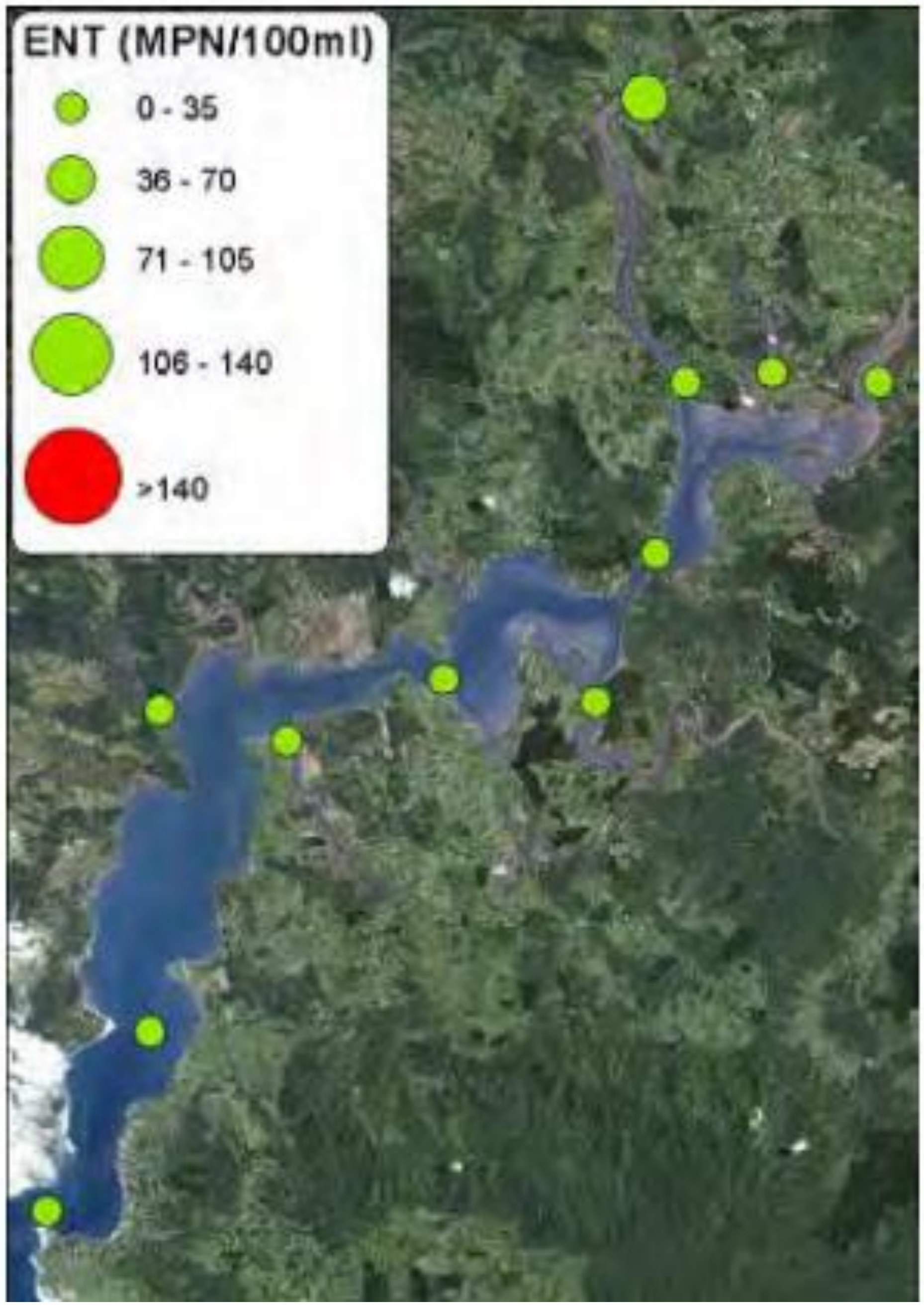

Figure 7. Enterococci levels (MPN/100mL) in the Hokianga Harbour, 2013 sampling.

Aside from results presented in existing reports above, I also assessed historical data routinely collected by the NRC. Available water quality data[3] 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[4]. 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 urban runoff, streams draining 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[5] 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*[6] (observed concentration on storm event day = 680 enterococci/100 mL).

[3] Northland Regional Council has routinely monitored 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, enterococci data has since 2009 been collected at the Hokianga Harbour Opononi site. 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.

[4] 2014/15-2019/20 bathing seasons, although Omapere at Old Wharf Road site has only been collected from 2018.

[5] The most recent data (5 year long, 2014-2019) are herein analysed in relation to the guidelines stipulated in MfE/MoH (2003), see Table 4 .

[6] Comments attached to Enterococci data recorded by NRC.

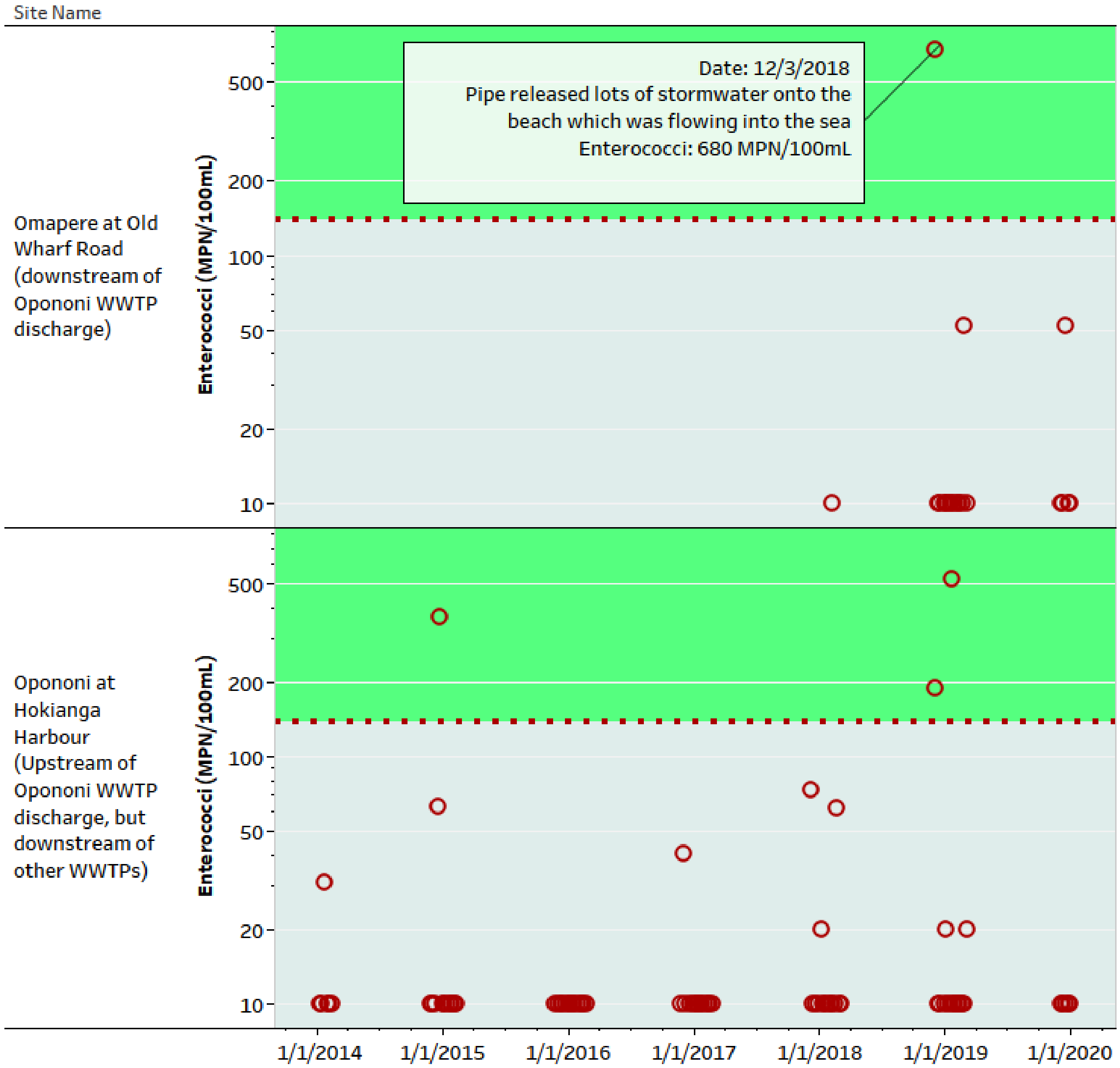

Figure 8. Enterococci concentrations of water samples collected at the Omapere at Old Wharf Road (upper image) and Hokianga Harbour Opononi (lower image) sites. Samples with enterococci concentrations below the acceptable enterococci concentrations of 140 enterococci/100 mL (Green mode) for marine waters are shaded in light blue, otherwise green[7].

[7] While enterococci data at the Omapere at Old Wharf Road site has only been collected since 2018, enterococci data has been collected since 2009 at the Hokianga Harbour Opononi site. Also, there are no data on sanitary inspection categories of the assessment site. Hence, I was not able to analyse the enterococci data based on MfE/MoH (2003) criteria using Microbiological Assessment and Sanitary Inspection Categories (MAC-SIC). Hence, the MfE/MoH (2003) criteria based on surveillance, alert and action levels for marine waters were adopted.

3.2.2 Shellfish microbiological quality

There are no provisions in the existing consent for shellfish tissue monitoring at the shellfish-gathering sites in the receiving environment. Nevertheless, an analysis of shellfish quality is important to assess the effects of the discharge on aquatic foods as they can become contaminated with faecal pathogens from exposure to contaminated water.

In New Zealand, FIB are used as a proxy for determining human health risk in relation to shellfish, these primarily being faecal coliforms (for shellfish-gathering waters) and *E. coli* (for shellfish tissues). While no specific microbiological guidelines exist for shellfish gathered for domestic (non-commercial) consumption, it is recommended that the commercial shellfish limits be applied in non-commercial settings[8] (New Zealand Food Safety Authority (NZFSA), 2006). These guidelines can be applied to point source-affected approved growing areas where relaying, depuration (Oliveira et al., 2011) or other post-harvest treatments are not required.

These guidelines stipulate that:

- Median Most Probable Number (MPN) of shellfish tissue *E. coli* must not exceed 230 *E. coli* per 100 g, and;
- Not more than 10% of the samples may present with shellfish tissue *E. coli* exceeding an MPN of 700 per 100g (NZFSA, 2006).

An alternative guideline not related to shellfish tissue but to shellfish-gathering waters is presented in the microbiological water quality guidelines for marine and freshwater recreational areas (MfE/MoH, 2003). According to these guidelines:

- The median FC content of samples taken over a shellfish-gathering season shall not exceed an MPN of 14/100 mL, and;
- Not more than 10% of samples should exceed an MPN of 43/100 mL (using a five-tube decimal dilution test).

These guidelines are expected to be applied in conjunction with a sanitary survey. There may be situations where bacteriological levels suggest that waters are safe, but a sanitary survey may indicate that there is an unacceptable level of risk.

As part of the Northland region's coastal monitoring exercise, NRC has conducted short-term monitoring of shellfish tissue quality at four selected sites in the Hokianga Harbour (see Section 3.2.1, Figure 4). According to the results of the study, shellfish flesh *E. coli*

[8] Animal Products (Regulated Control Scheme—Bivalve Molluscan Shellfish) Regulations 2006. http://www.legislation.govt.nz/regulation/public/2006/0038/latest/DLM369353.html?search=ts_regulation_bivalve_resel&sr=1

concentrations did not meet the relevant commercial guidelines at any of the four sites tested. Although medians were below 230 *E. coli*/100g at all sites, approximately 23-30% of individual samples exceeded the guideline value of 700 *E. coli* per 100g (Table 5). These results indicate that, at the time of sampling, <u>it was unsafe to consume shellfish harvested at these sites.</u>

Table 5. *E. coli* levels in shellfish flesh collected from the Hokianga Harbour between 2009 and 2010 (Source: NRC).

Site		Median	% of individual samples exceeding NZFSA guideline of 700 E. coli/100g
109685	Outer Mangamuka River and island	42.5	30
109686	South Kohukohu	61.5	23.3
109687	Rāwene Ferry Ramp	80.5	23.3
109692	Ōmāpere	78	24.4
NZFSA Guideline (*E. coli*/100g wet weight)		230	<10

4. Health Risk Assessment

4.1 Overview

The Health Risk Assessment in this study involved three key steps:

- Hazard analysis.
- Exposure assessment, including contaminant fate modelling.
- Effect analysis and risk characterization.

4.2 Hazard analysis

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

Because the tests for pathogens are time-consuming and expensive, it is not practical to implement such testing on a routine basis. Instead, regulatory bodies support testing for faecal indicator bacteria (FIB) (specifically enterococci and faecal coliforms) as a cost-effective means to assessing the quality of treated effluent. This position is supported by the assumption that most pathogens die at the same rate as FIB, and hence the numbers of FIB in the treated effluent can be used as an indicator (or proxy) for pathogens present in the treated effluent.

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

4.3 Exposure Assessment

Exposure assessment involves identification of populations that could be affected by pathogens. The main individuals at risk of exposure to pathogens in the receiving environment of the Kohukohu 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.

Ideally, a typical quantitative microbial risk assessment would involve the incorporation of dose-response models, consideration of how much water an individual will ingest or inhale over a period of time during a particular recreational activity; how much raw shellfish harvested from the impact sites that an individual will consume at one sitting; the amount, frequency, length of time of exposure, and doses for an exposure, to ultimately predict individual illness risks. In this case however a semi-quantitative approach was used instead for the microbial risk assessment. A semi-quantitative approach, in this case:

- Applies faecal indicator bacteria (enterococci-contact recreation, and *E. coli*-shellfish tissues, faecal coliforms-shellfish-gathering waters) as “conservative” proxies of pathogens relevant to public health risks.
- Assesses the impact of the discharge in terms of elevation of enterococci and FC concentrations in the receiving environment (by not including and including background concentrations).
- Assesses whether this increase in faecal indicator bacteria will be such that it causes the receiving environment to breach existing guidelines for contact recreation or shellfish-gathering.

4.3.1 Hydrodynamic modelling

MetOcean carried out 3-dimensional hydrodynamic modelling to predict how contaminants in the wastewater discharge plume will behave in the receiving water, with regards to dilution. Details of this modelling are already reported in MetOcean (2020). The model was based on a conservative tracer. The reasons for the use of a conservative tracer are supported by arguments related to UV inactivation in published literature (e.g. Jin and Flury, 2002; Linden et al., 2007; Silverman, 2013). The effectiveness of sunlight inactivation of waterborne pathogens depends on complex and variable environmental factors (e.g. the intensity and spectrum of sunlight), characteristics of the water containing the virus particles (e.g. pH, DO, ionic strength, source and concentration of photosensitizers), and peculiarities of the microbe. These concerns are well documented (Anders, 2006; Havelaar et al., 1993; Hijnen et al., 2006; Kohn et al., 2007; Kohn and Nelson, 2007; Love et al., 2010; Romero et al., 2011; Sinton et al., 2002, 1999). Despite the uncertainties associated with estimating the actual rates of UV inactivation that would take place in the receiving environment, it is certain that ultraviolet inactivation will occur. The hydrodynamic modelling approach to exclude solar radiation-based ultraviolet inactivation from the hydrodynamic module is thus, a highly precautionary approach, from a public health protection perspective. Consequently, the reported risks from this health risk assessment include the worst-case scenario and may be overstated.

It is important to note that an initial concentration of 1 was applied in the MetOcean hydrodynamic model such that the generated reciprocal dilution factors (in time series format, time scale = every 60 minutes for one year) could be scaled up to the varying concentrations of WWTP faecal coliforms concentrations during the microbial risk assessment.

4.3.2 Selection of exposure assessment sites

In consultation between SEL and staff at FNDC, 12 key sites were identified in the Hokianga Harbour for recreational water contact and harvesting of shellfish (Figure 9). These sites could be potentially impacted because of wastewater discharge. The selected exposure sites are: Sites M_1 and M_5 on Mangamuka River, Site M_3 on the Waihou River, Site M_2 (between Sites M_5 and M_3), Site M_4 (the closest to the Kohukohu wastewater discharge), Site M_6 (on the Tahehe River), Site M_8 (on Te Waipoka Stream), Site M_10 (on Whirinaki River), Site M_9 (adjacent Site 10) and Sites M_11 and M_12 which are further down the Harbour.

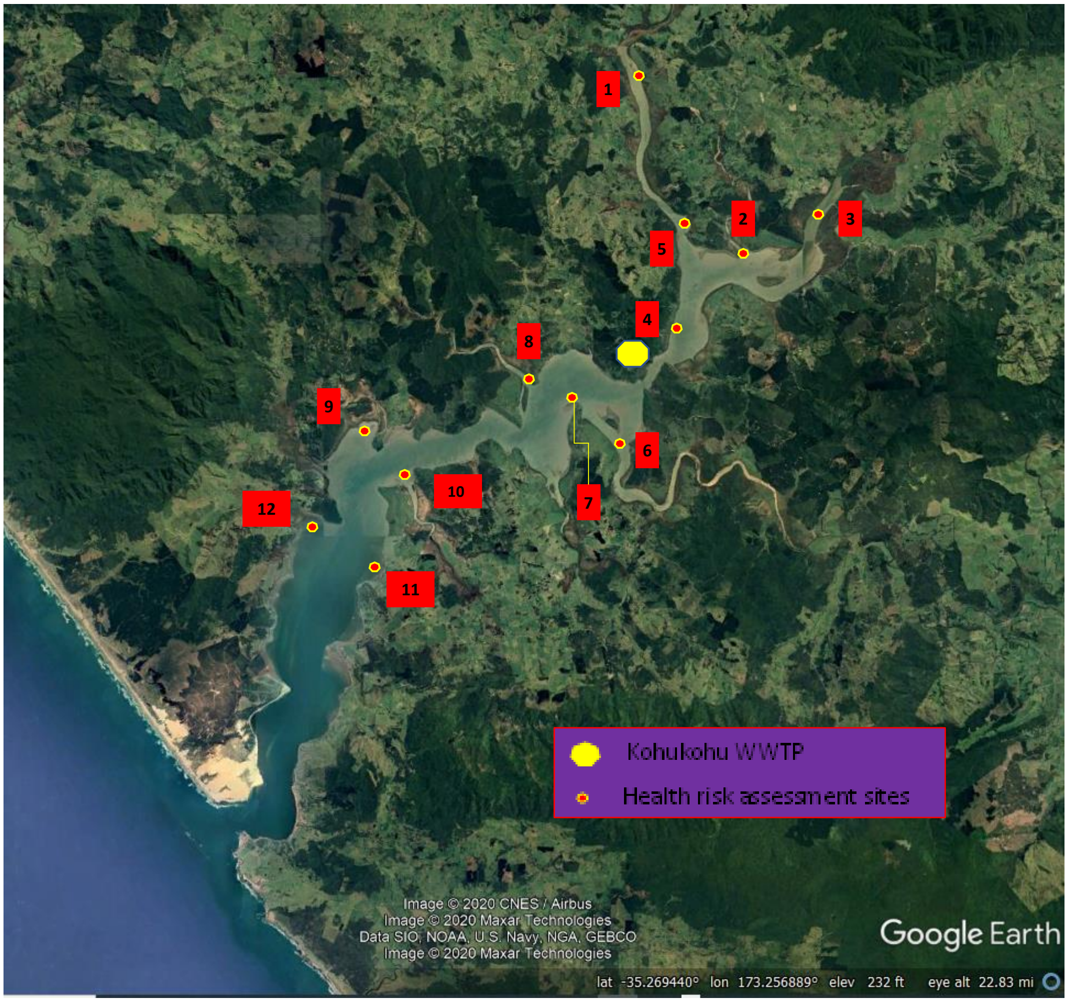

Figure 9. Location of the 12 selected exposure sites.

4.3.3 Dilutions achieved in the receiving environment

An analysis of dilutions supplied by MetOcean indicates that during El Niño conditions (Table 6) 50% of the time dilutions at the 12 sites during summer ranged from 26,561-fold to 47,546-fold. Slightly higher dilutions are achieved in the receiving environment at other times of the year[9]. For instance, 50% of the time, annual dilution at all the 12 sites ranged from 26,817-fold to 64,673-fold.

[9] Based on annual dilution data, Table 6.

During La Niña conditions (Table 7), dilutions achieved in the receiving environment were higher. Fifty percent of the time, summer dilution at the 12 sites ranged from 80,664-fold to101,456-fold.

Table 6. Dilutions of Kohukohu WWTP discharge achieved in the receiving environment during El Niño conditions.

Description	Percentile	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_10	M_11	M_12
El Niño annual	0.1	302,922	138,289	625,795	114,779	140,183	132,652	97,141	93,348	79,021	77,572	69,789	65,791
	0.2	134,821	79,316	285,875	64,039	84,232	69,505	54,721	53,392	45,533	44,186	38,838	35,946
	0.3	78,852	45,069	146,138	39,385	44,939	40,028	35,378	35,031	33,528	33,039	32,225	31,313
	0.4	52,223	37,943	89,788	34,206	38,036	34,248	31,885	31,401	30,108	29,772	29,181	28,645
	0.5	43,373	34,593	64,673	31,774	33,898	31,808	29,768	29,338	28,132	27,761	26,996	26,817
	0.6	38,353	32,736	51,683	30,406	32,235	29,812	28,397	28,116	27,383	27,174	26,728	26,520
	0.7	34,546	31,649	43,575	29,324	31,273	28,629	27,765	27,573	26,951	26,785	26,411	26,238
	0.8	32,102	30,515	38,085	28,540	30,367	28,027	27,383	27,165	26,410	26,328	26,030	25,815
	0.9	30,458	29,308	33,895	27,858	29,307	27,552	26,853	26,778	26,061	25,897	25,330	25,135
	0.95	29,480	28,703	31,624	27,488	28,653	27,201	26,640	26,576	25,747	25,558	24,979	24,637
	0.99	28,248	28,042	29,387	27,108	28,011	26,915	26,250	26,235	25,370	25,089	24,651	24,151
El Niño summer	0.1	80,668	40,785	220,830	34,595	41,243	33,966	32,282	31,757	30,587	30,261	29,712	29,076
	0.2	50,563	36,087	94,848	33,014	35,851	32,522	30,985	30,407	28,932	28,848	28,130	27,706
	0.3	43,072	34,218	68,717	31,760	33,758	31,284	29,888	29,540	28,340	28,006	27,085	26,877
	0.4	38,970	33,014	55,345	30,822	32,456	30,208	29,030	28,660	27,700	27,445	26,904	26,707
	0.5	36,187	32,258	47,546	30,173	31,689	29,229	28,397	28,177	27,448	27,224	26,776	26,561
	0.6	33,994	31,652	42,361	29,517	31,231	28,640	27,974	27,842	27,259	27,065	26,632	26,442
	0.7	32,413	30,913	38,251	28,947	30,682	28,214	27,681	27,561	27,037	26,844	26,473	26,257
	0.8	31,312	30,286	35,326	28,495	29,958	27,930	27,450	27,303	26,581	26,482	26,137	26,053
	0.9	30,218	29,430	33,077	28,014	29,427	27,624	26,985	26,893	26,333	26,230	25,923	25,720
	0.95	29,649	28,943	31,413	27,698	29,042	27,319	26,744	26,693	26,264	26,105	25,792	25,582
	0.99	28,818	28,546	29,661	27,229	28,546	26,881	26,471	26,418	26,061	25,839	25,422	25,388

Table 7. Dilutions of Kohukohu WWTP discharge achieved in the receiving environment during La Niña conditions.

Description	Percentile	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_10	M_11	M_12
La Niña annual	0.1	681639	247780	1417202	197095	266484	226052	161758	151029	120044	117567	106278	102220
	0.2	326048	141212	594936	112106	148920	134303	97222	94932	89730	89412	89012	89692
	0.3	190898	105058	342833	90585	108460	97032	85752	85027	84806	84251	83899	85152
	0.4	126376	93899	196560	86174	93527	86233	82635	81907	81140	80702	79714	80396
	0.5	104562	88474	137107	83140	88592	83663	79551	78631	76054	75955	74659	74464
	0.6	91607	84028	110643	78066	84586	79553	73928	72984	68494	68937	65243	66845
	0.7	85847	79017	97539	71885	79171	73563	67707	66348	62439	62303	60235	59319
	0.8	72094	65897	83646	62243	65349	63061	59938	59046	58606	58421	56434	55121
	0.9	58509	52900	67436	51673	52391	51172	49913	49533	49282	49094	48568	47104
	0.95	52548	50616	59545	48722	49926	47936	46861	46478	44481	44700	42576	41249
	0.99	49593	49211	52443	46375	49132	45850	44558	44462	42433	41549	40176	38901
La Niña summer	0.1	202710	129385	326485	108909	134311	106526	97746	96474	93070	92947	90781	96136
	0.2	125642	99374	164566	90695	99677	87882	87206	87047	88427	87687	88703	89520
	0.3	106779	92841	129894	87421	91764	85982	85044	84724	85018	84478	85279	87061
	0.4	94160	89190	110178	85649	88433	84552	83472	83131	83223	82988	82846	84541
	0.5	89480	85925	101456	83838	86309	83053	81866	81690	81214	80940	80774	81782
	0.6	86573	82347	93840	81095	81960	80688	80141	80270	79389	78969	77938	78394
	0.7	79873	78066	84119	76206	76609	75617	75630	76424	76539	76282	75647	75661
	0.8	64141	63621	70526	66267	62942	67987	70692	71827	70357	71195	70621	71025
	0.9	57667	53953	63354	54593	53600	54897	57009	57187	62391	62903	65029	68923
	0.95	53461	51970	57715	52275	51543	52779	53953	54325	56526	58502	62292	64865
	0.99	50271	50345	52285	49697	50038	49589	50036	49891	51140	51772	54601	55495

4.4 Effect analysis and risk characterisation

To estimate final faecal coliform concentrations for each of the 12 exposure sites, percentile distributions of the reciprocal dilution factors from the hydrodynamic modelling was multiplied by the concentrations of the treated effluent discharged from Kohukohu WWTP. This approach has been used in several previous microbial risk assessment studies (e.g. Dada 2018a, b ,2019a, b, c, 2020, McBride 2011, 2012, 2013, 2016a,b).

The goal was to determine:

- If the resulting enterococci concentrations in the receiving water (after including background concentrations) exceed limits for recreational water quality specified in the microbiological water quality guidelines for marine and freshwater recreational areas (MfE/MoH, 2003).
- If the discharge will cause the receiving water to exceed limits for shellfish-gathering areas specified in MfE/MoH (2003).

We note that the current consent is based on FC compared to enterococci as is used for recreational water guidelines in MfE/MoH (2003). While FC may be an appropriate indicator for the effluent, it becomes a challenge to apply dilutions to the wastewater concentrations in a way that causally relates to enterococci guidelines for recreation in the receiving water.

Despite this concern, we consider it conservative to apply FC concentrations as "presumed equivalent enterococci concentrations" of the treated effluent. This stance is supported by literature. First and foremost, FC concentration usually exceeds or compares with enterococci concentration in sewage and in receiving marine environment. In an investigation of human sewage pollution at Florida Gulf coast Beaches impacted by WWTP discharges (Korajkic et al., 2011), water column enterococci concentrations generally exceeded FC concentrations at all sites tested. In another study that compared concentrations and population diversity of the bacterial groups analysed in the raw (RS) and treated sewage (TS) from five wastewater plants, FC concentration usually exceeded enterococci concentration in sewage at all wastewater plants tested (Vilanova et al., 2004). Secondly, and according to the MfE/MoH (2003) policy document, "while enterococci are easily damaged in WSPs (Davies-Colley et al 1999), FC that emerge from a pond appear to be more sunlight resistant than those that enter it (Sinton et al 1999). Thus, WSP enterococci are inactivated in receiving water faster than WSP FC (Sinton et al 2002)." Our position in this study to apply FC concentrations as conservative estimates of enterococci is thus well supported by literature.

Wastewater concentrations containing different scenarios of FC concentrations were applied:

i. Consent-specified limit for effluent FC concentrations (i.e. 15,000 CFU/100mL).
ii. Worst-case (95th percentile) FC concentration (i.e. 24,400 CFU/100mL).

These scenarios invariably represent:

i. Current normal condition of the plant when consents limits are not exceeded.
ii. Current worst-case condition of the plant (based on 95th percentile concentrations recorded at the plant).

4.5 Recreational health risk

4.5.1 Current normal plant condition when consents limits are not exceeded

The existing consent limit is set at 15,000 CFU/100mL (see Section 2.3).

Assuming no background concentrations, when treated wastewater containing enterococci equivalent concentrations (i.e. FC concentrations) of 15,000 CFU/100mL is continuously discharged into the Hokianga Harbour from Kohukohu WWTP, only very marginal increases in enterococci at all 12 sites will be observed. The maximum increase of enterococci predicted as a result of the WWTP discharge is 1 CFU/100mL during El Niño and La Niña conditions (Table 8, Table 9). The effect of the discharge on recreational water quality is thus negligible.

Based on an analysis of the receiving water quality, 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 (see Section 3.2.1). This indicates that in terms of recreation, the water at sites closest to the Hokianga Harbour outlet was generally of acceptable quality. Hence, background concentrations of 70 enterococci/100 mL could be considered representative of the receiving environment baseline concentration. I note however, that the concentrations upstream may be higher, for example, at sites further into the harbour, where comparatively lower tidal influence and higher catchment influence may contribute to elevated FIB concentrations.

Assuming background concentrations of 70 enterococci/100 mL, when treated wastewater containing enterococci equivalent concentrations (i.e. FC concentrations) of 15,000 CFU/100mL *or* less is continuously discharged into the Hokianga Harbour from Kohukohu WWTP, enterococci will not exceed 71 enterococci/100 mL during La Niña and El Niño conditions. It is thus predicted that all 12 sites will not exceed the 140 CFU/100mL limit specified for "Acceptable/Green (surveillance) Mode" specified in the MfE/MoH (2003) policy document.

Based on the high levels of dilutions at the receiving sites, consistent with the hydrodynamic modelling, these results show that the Kohukohu WWTP does not negatively impact recreational water quality at all 12 assessed sites when discharge containing indicator bacteria concentrations at or below the current consent limit of 15,000 CFU/100mL is continuously released into the Hokianga Harbour.

Table 8. Predicted increases in FC concentrations (CFU/100mL) in the receiving water as a result of the Kohukohu WWTP discharge when the existing consent limits of 15,000 CFU/100mL <u>are not exceeded</u> during El Niño conditions.

		Site											
Scenario	Percentile	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_10	M_11	M_12
El Niño annual	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	30th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	40th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1	+1
	50th	+0	+0	+0	+0	+0	+0	+1	+1	+1	+1	+1	+1
	60th	+0	+0	+0	+0	+0	+1	+1	+1	+1	+1	+1	+1
	70th	+0	+0	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1
	80th	+0	+0	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1
	90th	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	95th	+1	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	99th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
El Niño summer	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1	+1	+1
	30th	+0	+0	+0	+0	+0	+0	+1	+1	+1	+1	+1	+1
	40th	+0	+0	+0	+0	+0	+0	+1	+1	+1	+1	+1	+1
	50th	+0	+0	+0	+0	+0	+1	+1	+1	+1	+1	+1	+1
	60th	+0	+0	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1
	70th	+0	+0	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1
	80th	+0	+0	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	90th	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	95th	+1	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	99th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1

Table 9. Predicted increases in FC concentrations (CFU/100mL) in the receiving water as a result of the Kohukohu WWTP discharge when the existing consent limits of 15,000 CFU/100mL are not exceeded during La Niña conditions.

		Site											
Scenario	Percentile	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_10	M_11	M_12
La Niña annual	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	30th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	40th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	50th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	60th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	70th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	80th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	90th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	95th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	99th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
La Niña summer	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	30th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	40th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	50th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	60th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	70th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	80th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	90th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	95th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	99th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0

4.5.2 Worst-case current condition (95th percentile enterococci-equivalent concentration)

Between 2010 and 2019, the Kohukohu WWTP discharge had a 95th percentile FC concentration of 24,400 CFU/100mL (Table 3).

When treated wastewater containing enterococci equivalent concentrations (i.e. 95th percentile FC concentrations) of 24,400 CFU/100mL is continuously discharged into the Hokianga Harbour from Kohukohu WWTP, only very marginal increases (+1 CFU/100mL, Table 10, Table 11) in enterococci at all 12 sites will be observed. during El Nino and La Nina conditions. The effect of the discharge is thus negligible.

Assuming background concentrations of 70 enterococci/100 mL, when treated wastewater containing enterococci equivalent concentrations (i.e. 95th perc. FC concentrations) of *24*,400 CFU/100mL is continuously discharged into the Hokianga Harbour from Kohukohu WWTP, 99 percent of the time, enterococci will not exceed 71 enterococci/100 mL during La Nina El and Niño conditions. It is thus predicted that all 12 sites will not exceed the 140 CFU/100mL limit specified for “Acceptable/Green (surveillance) Mode” specified in the MfE/MoH (2003) policy document.

Table 10. Predicted increases in FC concentrations (CFU/100mL) in the receiving water as a result of the Kohukohu WWTP discharge when effluent containing 95th percentile FC concentrations of 24,400 CFU/100mL is discharged into the Hokianga Harbour during El Niño conditions.

		Site											
Scenario	Percentile	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_10	M_11	M_12
El Niño annual	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1	+1	+1
	30th	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	40th	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	50th	+1	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	60th	+1	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	70th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	80th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	90th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	95th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	99th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
El Niño summer	10th	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	20th	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	30th	+1	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	40th	+1	+1	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1
	50th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	60th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	70th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	80th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	90th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	95th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	99th	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1

Table 11. Predicted increases in FC concentrations (CFU/100mL) in the receiving water as a result of the Kohukohu WWTP discharge when effluent containing 95^{th} percentile FC concentrations of 24,400 CFU/100mL is discharged into the Hokianga Harbour during La Niña conditions.[1]

		Site											
Scenario	Percentile	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_10	M_11	M_12
La Niña annual	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	30th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	40th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	50th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	60th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	70th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	80th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	90th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1
	95th	+0	+0	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1
	99th	+0	+0	+0	+1	+0	+1	+1	+1	+1	+1	+1	+1
La Niña summer	10th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	20th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	30th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	40th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	50th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	60th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	70th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	80th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	90th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	95th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0
	99th	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0

4.6 Shellfish consumption health risk

In terms of shellfish tissue *E. coli* concentrations, the quality of shellfish at the Hokianga sites currently does not meet the New Zealand Food Safety Authority (NZFSA) 2006 guidelines (see section 3.2.2). For instance, approximately 23-30% of individual samples exceeded the NZFSA guideline value of 700 *E. coli* per 100g (Table 5).

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 is only +1 CFU/100mL. Given this negligible change in water quality, <u>the discharge is not expected to significantly affect shellfish quality</u>.

It is however important to emphasise that shellfish filter feed. 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 so many factors including, the species being considered, their differing body sizes, tissue physiological composition, filtration activity etc (Grodzki et al 2014). Nonetheless, on the average, an increase of +1 CFU/100mL of faecal coliforms[10] in the water column may still translate into higher concentrations in the shellfish tissues.

From a mere 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 are likely contributing to the elevated *E. coli* concentrations, 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.

It is 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

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[10] Assuming a conservative approach that most of the faecal coliforms are *E. coli*. Ideally, *E. coli* is a species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals. Some literature have reported up to 90% of the fecal coliforms being E. coli (Hachich et al 2012).

in the Hokianga Harbour, as land use may differ significantly in their contributory catchments.

5. Conclusion

Results from this study show that enterococci in the current Kohukohu WWTP discharge with a worst-case (95^{th} percentile) concentration of 24,400 CFU/100mL does not negatively impact recreational water quality. Based on dilutions achievable occurring at in the Hokianga Harbour, increases in faecal coliform in the receiving water due to the discharge from Kohukohu WWTP – 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. The quality of shellfish at the Hokianga sites currently does not meet the New Zealand Food Safety Authority (NZFSA) 2006 guidelines. As stated above, based on the worst-case scenario of Kohukohu WWTP discharge the maximum change in faecal coliform in the receiving water is + 1 CFU/100mL. Given this negligible change in water quality, <u>the discharge is not expected to significantly affect shellfish quality</u>.

6. Limitations and Recommendation

While focus has been placed on faecal indicator bacteria (FIB) concentrations as a "yardstick" for health risk assessment in this study, limitations associated with the use of indicator bacteria as proxies for viruses is well documented (Wade et al. 2008, Wade et al. 2010, USEPA 2015) (USEPA, 2015; Wade et al., 2010, 2008). Furthermore, as most standard sewage treatment processes are not efficient in eliminating viruses, treated sewage may still contain concentrations of enteric viruses that present a significant public health risk (Lodder et al., 2010; Okoh et al., 2010). Several enteric viruses have been described in published literature as associated with outbreaks due to exposure to polluted recreational water (Jiang et al., 2007; Sinclair et al., 2009; USEPA, 2015). These include noroviruses, adenoviruses, hepatitis A viruses, echoviruses and Coxsackie viruses (Hauri et al., 2005; Lodder et al., 2010). Literature has also suggested that the greatest public health risk linked with the discharge of treated wastewater relates mainly to viruses (Courault et al., 2017; Prevost et al., 2015). A unique characteristic of viral infections is that a high proportion of the exposed populations could be potentially affected, often leading to very high incidences of gastroenteritis that can then be spread by person-to-person contact to other individuals who were not directly exposed to the polluted waters (Patel et al., 2008; Widdowson et al., 2005). Notwithstanding the limitations of this current study (i.e. the use of faecal indicator bacteria as proxies for pathogens), if a determination of health risks due to viruses is required, a quantitative microbial risk assessment would be required. This would incorporate consideration of pathogen dose-response curves and amounts of water or shellfish ingested by those who use the water for recreational or shellfish-gathering purposes.

In this study, a conservative approach backed by available literature was to presumptively apply FC concentrations of the treated effluent as "assumed enterococci concentrations" while assessing recreational health risks due to the discharge. This position may not necessarily hold. To resolve these uncertainties, I recommend that a six-month study be commissioned with samples collected fortnightly with a view to comparing concentrations and population diversity of the indicator bacterial groups (enterococci and faecal coliforms) in the treated sewage from the Kohukohu WWTP.

I recommend a faecal source tracking study to resolve the uncertainty associated with elevated faecal indicator bacteria concentrations in shellfish tissues collected at the harbour, as was successfully applied in the Whangaroa Harbour study (Reed 2011).

On the whole, while the results from this study indicate that the Kohukohu discharge is associated with very minor change in faecal indicator bacteria concentrations, careful consideration needs be given to faecal pollutants contributed from other sources in the catchment, for instance, other wastewater treatment plants and catchment inflows into the harbour.

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