Quantitative Microbial Risk Assessment (QMRA) of the AFFCO Rangiuru Plant discharge and receiving environment

October 2020

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Executive Summary

AFFCO Rangiuru Plant is seeking renewal of consents to continue discharging treated meatworks wastewater into the Kaituna River. To support the new discharge consent application, AFFCO has contracted QMRA Data Experts through ArgoEnvironmental Ltd to assess the potential effects of the meatworks discharges on the receiving environment. Increasingly, where discharges may contain a significant concentration of microorganisms that could impact upon public health, regional councils are requiring assessments that go beyond the traditional method of conformity to faecal indicator bacteria (FIB) guidelines. This study therefore seeks to provide a scientifically robust assessment, of whether the AFFCO Rangiuru Plant discharges have a 'more than minor' effect on the state of the receiving environment for recreational uses and shellfish harvesting .

The project proceeded in the following phases.

- Collation of existing information on microbial contaminants from the AFFCO Rangiuru Plant FIB compliance monitoring and the wider receiving environment (the Kaituna River), as well as targeted pathogen monitoring between 2014-2017). This data was used to describe the current microbial status of the AFFCO Rangiuru Plant discharge and the Kaituna River receiving environment. Baseline (upstream) and post-discharge river concentrations (downstream) were assessed against relevant water quality guidelines for recreational waters (i.e. the revised 2020 National Policy Statement for Freshwater Management and MfE/MoH 2003).
- Mass balance modelling in which treated wastewater concentrations of FIB in AFFCO Plant wastewater were combined with FIB data for receiving waterbody upstream of the discharge to predict how the discharged wastewater will affect the faecal bacteria load in the Kaituna river. To cover seasonal variabilities that are typically associated with environmental data, distributions of these input parameters and Monte Carlo simulations were embedded in the mass balance calculations. This probabilistic modelling approach capture all scenario from worst to best case scenarios of wastewater flow rate, wastewater concentrations, receiving water flow rate and receiving water FIB concentrations. Results from previous mixing studies have already shown that the treated wastewater is fully mixed 350m downstream of the discharge point. As the mass balance modelling approach typically assumes full mixing (100% mixing), additional scenarios of mixing (i.e., 1%, 5%, 10%, 25% and 50% mixing) were included to model effects during river edge flow or accumulation within the mixing zone.
- Completion of a quantitative microbial risk assessment modeling (QMRA) using predefined dose-response functions for zoonotic bacterial and protozoan pathogens relevant to human health (*Salmonella*, *Campylobacter*, *E. coli* 0157: H7, *Giardia*, *Cryptosporidium*). Risk profiles were compared with guidelines established in the New Zealand "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*" (MfE/MoH 2003): that is, high illness risk (>10%

gastrointestinal (GI) illness); moderate illness risk (5-10% GI illness); low illness risk (1-5% GI illness); and the "no observable adverse effects level (<1%).

Summary of microbial characteristics of the discharge water

- Seasonally decomposed time series analysis of historical data (1997-2020) indicates that the microbiological quality of the AFFCO Rangiuru Plant wastewater has increased over the years as a result of various improvements in the treatment applied to the wastewater before the discharge.
- None of the 289 weekly samples collected between 2015 and 2020 exceeded the consent monthly limit (100% compliance level). The 13-week running median limit of enterococci of 5,000 per 100mL stipulated in the existing consent was also not exceeded during the period (100% compliance level).

Summary of microbiological quality downstream of the receiving environment

Compliance in terms of proportions of samples below the 273 *E.coli* per 100mL threshold specified in the existing discharge consent has generally improved over the years. For instance, nearly 80% of samples collected in 2002 at the Kaituna River site downstream of the discharge exceeded 273 *E.coli* per 100mL, compared to more recent years where less than 20% exceedance was observed (with the exception of 2016). Instances of *E.coli* concentrations downstream (200 CFU/100mL) being higher than that of the discharge (80 CFU/100mL), and of elevated *E.coli* concentrations downstream (7100 CFU/100mL) were observed on 18/2/2016 following heavy rainfall (76.5 mm) on the sampling day and the day prior to sampling (10mm), indicating that other catchment sources were contributing to the contaminant load downstream of the discharge during extreme precipitation events.

Summary of dilution achieved in the receiving environment

Outside the mixing zone where 100% of dilution is achieved, mass balance modelling predicts that 50 percent of the time, the AFFCO Plant discharge will be diluted 1,322-folds in summer and 1,755-folds at other times of the year.

Within the mixing zone, varying lower levels of dilution is achieved. For instance, it is predicted that, if 50% dilution is achieved, 50 percent of the time, the AFFCO Plant discharge will be diluted by 661-folds in summer and 878-folds at other times of the year.

Summary of effect of discharge on *E.coli* and NPS-FM attribute state

- On the whole, the results of mass balance modelling show that the release of treated animal works wastewater produced by AFFCO Plant Rangiuru does not increase the *E. coli* concentrations in the receiving Kaituna River water to the extent that it causes an NPS-FM attribute state change, even during the worst-case scenario of reduced dilution at the river banks within the mixing zone. In terms of swimmability from an NPS-FM perspective, these results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge on the Kaituna River *E.coli* levels is **not more than minor.**

Summary of QMRA: Risk associated with swimming

Quantitative microbial risk assessment (QMRA) was used to evaluate the risk to swimmers in the Kaituna River, at the compliance site 350m downstream of the AFFCO discharge where it has been established that 100% mixing occurs and within the mixing zone where a range of dilution (1%, 5%, 10%, 25% and 50%) may potentially occur. The results of QMRA analysis generally show that **within the mixing zone (within** 350m downstream of the discharge) and outside of the mixing zone (i.e. 350m downstream of the discharge and beyond), a combination of wastewater treatment and the effect of dilution of the discharged wastewater occurring in the receiving environment is sufficient to reduce the individual illness risk (IIR) profiles to very low levels (below 0.2% in most cases).

Risk profiles associated with swimming were below the "no observable adverse effects level" (1% threshold) for all the zoonotic pathogens tested. Even during slightly lower dilutions occurring in summer, the IIR was below the 1% threshold. These results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge on the Kaituna River is **not more than minor** in terms of health risks associated with swimming.

Summary of QMRA: Risk associated with consumption of raw shellfish

There is no information on the existence of shellfish gathering areas in the receiving water; neither are there provisions in the existing consent for shellfish tissue monitoring in the receiving environment. Nevertheless, an analysis of shellfish quality is important to assess the effects of the discharge on aquatic foods in the Kaituna River as they can become contaminated with faecal pathogens from exposure to contaminated water.

Outside the mixing zone

The results of QMRA analysis generally show that outside of the mixing zone (i.e. 350m downstream of the discharge and beyond), a combination of wastewater treatment and the effect of dilution of the discharged wastewater occurring in the receiving environment is sufficient enough to reduce the individual illness risk profiles to very low levels (below

0.2% in most cases). Risk profiles associated with consumption of raw shellfish were below the "no observable adverse effects level (NOAEL)" i.e. 1% threshold for all the zoonotic pathogens tested. Even during slightly lower dilutions occurring in summer, the IIR was below the 1% threshold. These results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge is **not more than minor** in terms of health risks associated with consumption of raw shellfish harvested at the Kaituna River.

Within the mixing zone

The results of QMRA analysis generally show that within the mixing zone (i.e. within 350m downstream of the discharge), enteric illness risks as a result of the discharge range from below NOAEL to high, depending on the level of dilution achieved, viz:

- If 50% dilution is achieved, low enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment only during summer months that are characterized by comparatively lower flows.
- If 25% or 10% dilution is achieved, regardless of the season, low enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment.
- If 5% dilution is achieved, low enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment. However, during summer months, illness risks increase from low to moderate.
- If 1% dilution is achieved, regardless of the season, high enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment.

On the whole, the current study fills some crucial study gaps in the animal wastewater risk assessment terrain, as it shows using a robust microbiological monitoring program (FIB: 1995-date, pathogens: 2014-2017) and quantitative risk assessment that the contribution the discharge makes to the health risk associated with contact recreation and consumption of raw shellfish harvested downstream in the Kaituna river is negligible, particularly outside of the mixing zone (i.e. 350m downstream of the discharge and beyond).

When evaluating these results, attention should be given to the absence of recreational activity (swimming) in the Kaituna River for a distance of 1,500 m downstream from the discharge point. As these QMRA results predict no observable adverse effects level beyond the 350m mark where 100% dilution is achieved, we predict that there will be no more than minor effects at the swimming site situated about 1500m downstream of the discharge. Also, in terms of the public health impact at the estuary, there will be no more than minor effects as a result of the discharge.

1. Introduction

AFFCO Rangiuru Plant is seeking renewal of consents to continue discharging treated meatworks wastewater into the Kaituna River. To support the new discharge consent application, AFFCO has contracted QMRA Data Experts through ArgoEnvironmental Ltd to assess the potential effects of the meatworks discharges on the receiving environment. Increasingly, where discharges may contain a significant concentration of microorganisms that could impact upon public health, regional councils are requiring assessments that go beyond the traditional method of conformity to faecal indicator bacteria (FIB) guidelines. This study therefore seeks to provide a scientifically robust assessment, of whether the AFFCO Rangiuru Plant discharges have a 'more than minor' effect on the state of the receiving environment.

The project proceeded in the following phases.

- Collation of existing information on microbial contaminants from the AFFCO Rangiuru Plant FIB compliance monitoring and the wider receiving environment (the Kaituna River), as well as targeted pathogen monitoring between 2014-2017). This data was used to describe the current microbial status of the AFFCO Rangiuru Plant discharge and the Kaituna River receiving environment. Baseline (upstream) and post-discharge river concentrations (downstream) were assessed against relevant water quality guidelines for recreational waters (i.e. the revised 2020 National Policy Statement for Freshwater Management and MfE/MoH 2003).
- Mass balance modelling in which treated wastewater concentrations of FIB in AFFCO Plant wastewater were combined with FIB data for receiving waterbody upstream of the discharge to predict how the discharged wastewater will affect the faecal bacteria load in the Kaituna river. To cover seasonal variabilities that are typically associated with environmental data, distributions of these input parameters and Monte Carlo simulations were embedded in the mass balance calculations. This probabilistic modelling approach capture all scenario from worst to best case scenarios of wastewater flow rate, wastewater concentrations, receiving water flow rate and receiving water FIB concentrations. Results from previous mixing studies have already shown that the treated wastewater is fully mixed 350m downstream of the discharge point. As the mass balance modelling approach typically assumes full mixing (100% mixing), additional scenarios of mixing (i.e., 1%, 5%, 10%, 25% and 50% mixing) were included to model effects during river edge flow or accumulation within the mixing zone.
- Completion of a quantitative microbial risk assessment modeling (QMRA) using predefined dose-response functions for zoonotic bacterial and protozoan pathogens relevant to human health (*Salmonella*, *Campylobacter*, *E. coli* 0157: H7, *Giardia*, *Cryptosporidium*). Risk profiles were compared with guidelines established in the New Zealand "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*" (MfE/MoH 2003)

Effects determined in this study are in relation to recreational uses and consumption of raw shellfish harvested in the receiving Kaituna River. We note that there is no information on the existence of shellfish gathering areas in the receiving water; neither are there provisions in the existing consent for shellfish tissue monitoring in the receiving environment. Nevertheless, an analysis of shellfish quality is important to assess the effects of the discharge on aquatic foods in the Kaituna River as they can become contaminated with faecal pathogens from exposure to contaminated water.

This report is presented in topical sections. Section 2 presents a discussion on the microbial characteristics of the AFFCO Rangiuru wastewater in relation to existing resource consent limits, based on historical and current monitoring data. Section 3 discusses the characteristics of the receiving environment in relation to the existing consent requirements. Section 4 covers the methodology and results of mass balance modelling used to predict the effects of the AFFCO discharge in terms of FIB loadings. Section 5 presents the methodology and discusses the results of the quantitative microbial risk assessment modeling (QMRA), covering health risks associated with swimming and consumption of raw shellfish harvested from the Kaituna River receiving environment. A conclusion is presented in Section 6.

2. Characteristics of the AFFCO Rangiuru Plant discharge water

2.1 Discharge volumes of AFFCO Plant effluent

Analysis of AFFCO Rangiuru Plant flow monitoring data (1997-2020) indicates that:

- Regardless of the season, effluent flow ranged from 0 m^3/s (no discharge days) to 0.111 m^3/s, with an overall median of *0.019* m^3/s (Table 1). During summer months, a slightly higher effluent median flow of *0.023* m^3/s was recorded.
- For the majority (95%) of the time, the effluent flow rate was below 0.05 m^3/s (Table 1).

Table 1. Descriptive summary of AFFCO Rangiuru Plant effluent flow rate (1997-2020)

	Observed flow (m3/s)	
Statistics	1997-2000 (year-round)	1997-2000 (summer months only)
Minimum	0.000	0.000
5th percentile	0.001	0.002
Median	0.019	0.023
75th percentile	0.027	0.030
95th percentile	0.047	0.050
Maximum	0.111	0.111

2.2 Analysis of wastewater FIB data

In line with condition 7.2 of the existing consent (24932), AFFCO Rangiuru Plant collects samples of treated effluents prior to discharge into the Kaituna River. These samples are analysed for a suite of parameters including *E.coli* and enterococci. Seasonally decomposed time series analysis of historical data (1997-2020) indicates that microbiological quality of the AFFCO Rangiuru Plant wastewater has improved over the years as a result of various improvements in the treatment applied to the wastewater before the discharge. For instance, declining trends were observed for wastewater enterococci and *E.coli* concentrations over the years (Figure 1 and Figure 2).

In the more recent years (2015-2020), the *E.coli* concentration of the treated wastewater prior to discharge ranged from 2 CFU/100mL to 20,000 CFU/100mL (Table 2). Generally higher concentrations were recorded in summer than in other months of the year. For example, the 95th percentile *E.coli* concentration was 4,280 CFU/100mL in the summer months, compared to 2,920 CFU/100mL recorded regardless of the season (Table 2). Similarly, the 95th percentile enterococci concentration was 7,360 CFU/100mL in the summer months, compared to 4,760 CFU/100mL recorded regardless of the season (Table 3). This observation indicates that health risk assessments related to the discharge would need to give additional consideration to the summer months.

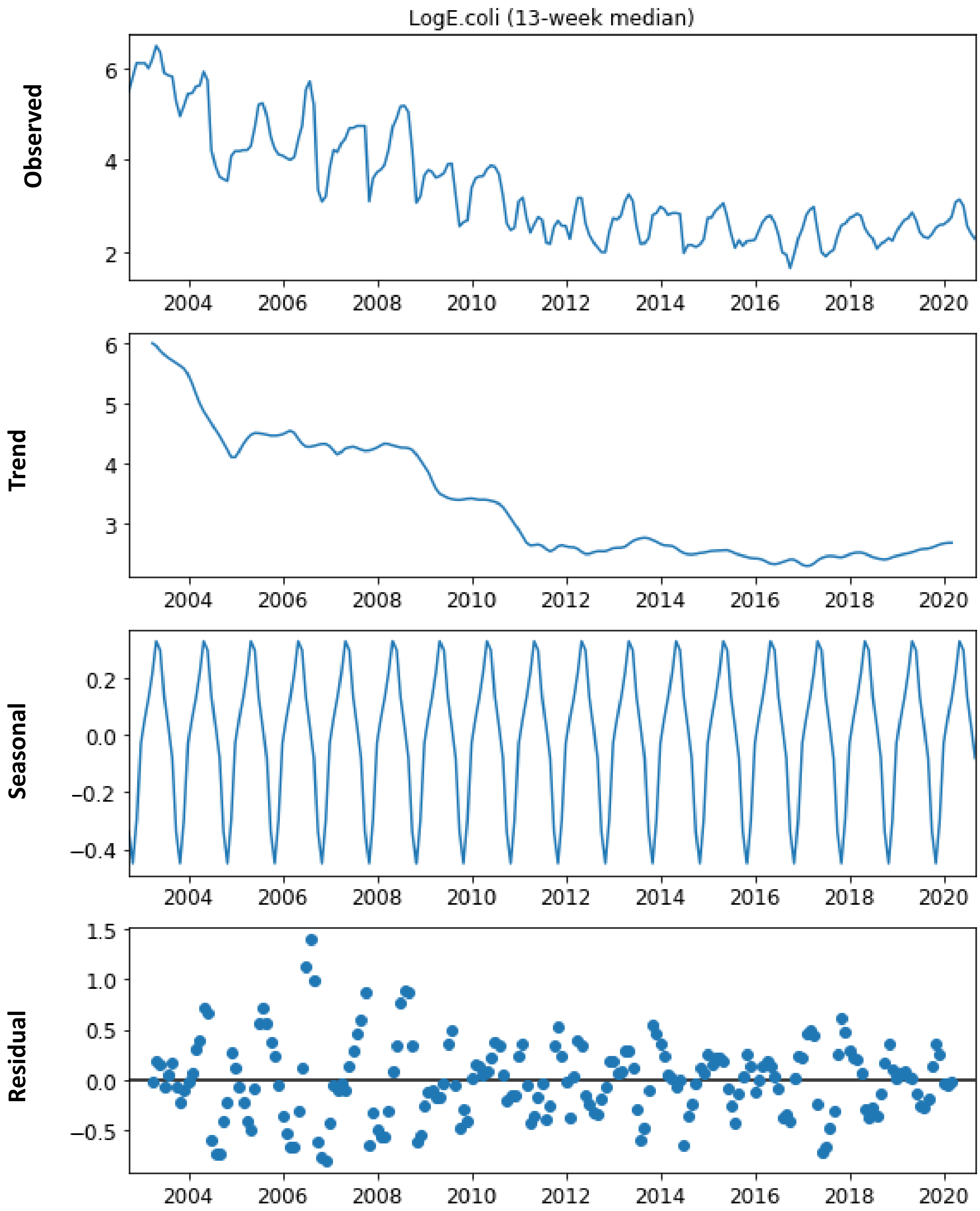

Figure 1 Seasonally decomposed time series analysis of AFFCO Rangiuru plant wastewater *E.coli* data (2003-2020)

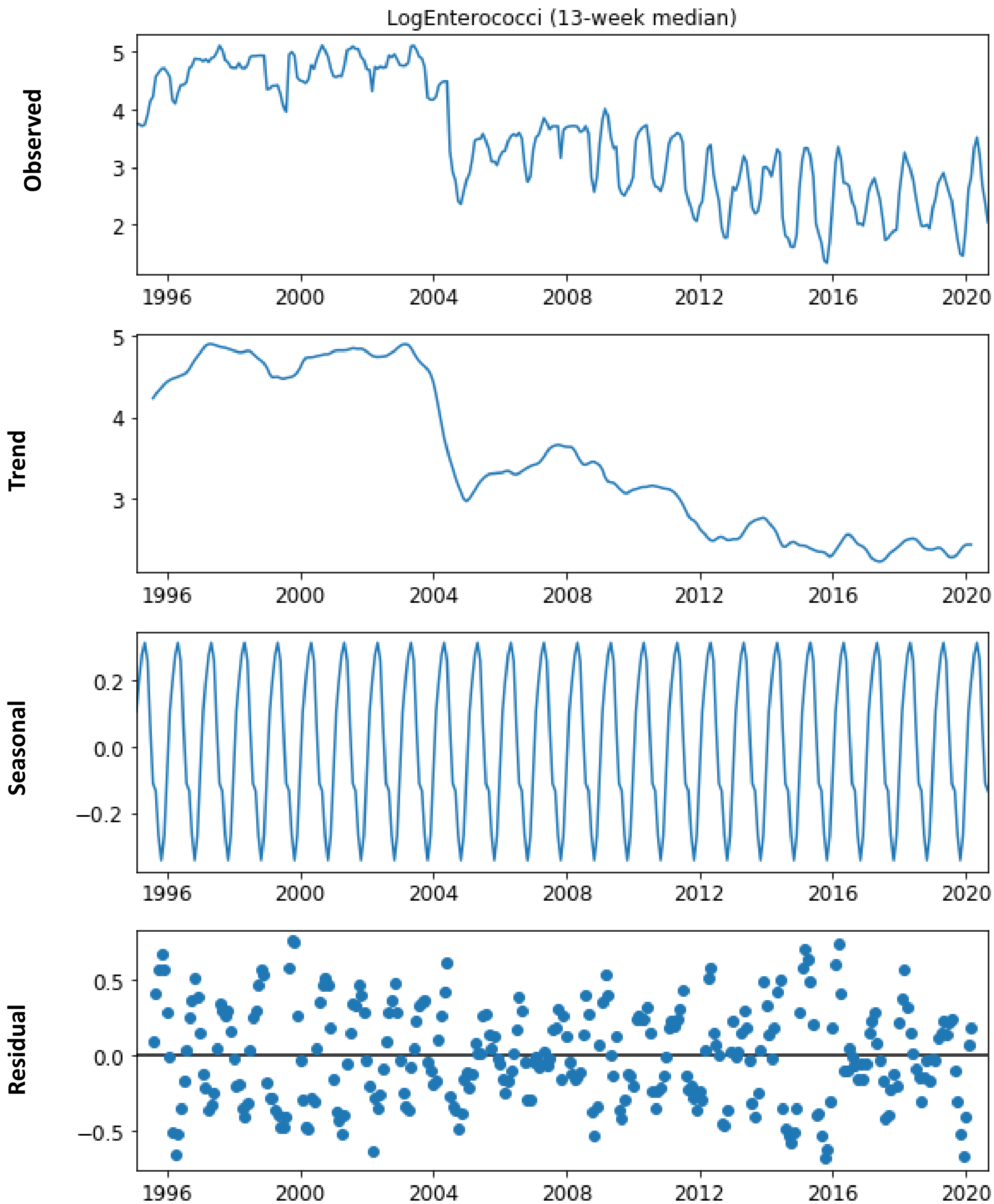

Figure 2 Seasonally decomposed time series analysis of AFFCO Rangiuru plant wastewater Enterococci data (1997-2020)

Table 2. Descriptive summary of AFFCO Rangiuru Plant wastewater weekly *E.coli* concentrations (2015-2020)

Statistics	Observed *E.coli* (CFU/100mL)	
	2015-2000 (year-round)	2015-2020 (summer months only)
Minimum	2	2
5th percentile	28	100
Median	300	600
75th percentile	660	1300
95th percentile	2920	4280
Maximum	20000	20000

Table 3. Descriptive summary of AFFCO Rangiuru Plant wastewater weekly Enterococci concentrations (2015-2020)

Statistics	Observed Enterococci (CFU/100mL)	
	2015-2000 (year-round)	2015-2020 (summer months only)
Minimum	2	4
5th percentile	13	46
Median	285	660
75th percentile	785	2200
95th percentile	4760	7360
Maximum	16000	16000

2.3 FIB comparison with existing consent condition limits

Condition 8.10 of the current resource consent (Consent No. 24932) stipulates that:

- The 13-week running median concentration of enterococci should not exceed 5,000 per 100mL, and;
- The concentration of enterococci in any one wastewater sample should not exceed 20,000 per 100 mL.

None of the 289 weekly samples collected between 2015 and 2020 exceeded the consent monthly limit (100% compliance level). The 13-week running median concentration of enterococci of 5,000 per 100mL was also not exceeded during the period (100% compliance level) (Figure 3).

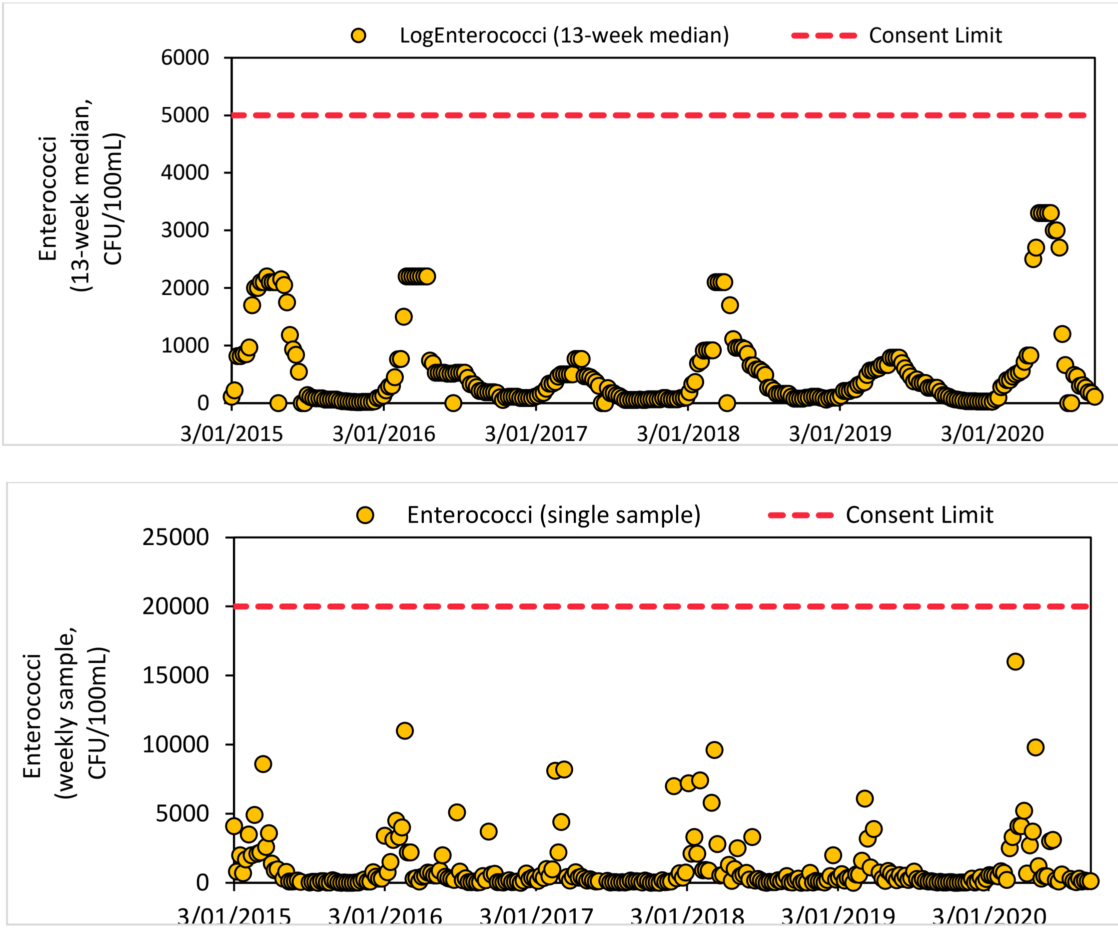

Figure 3. Compliance based on AFFCO Rangiuru Plant wastewater (2015-2020) 13-weekly median enterococci concentrations (top) and weekly enterococci concentrations (bottom).

3. Characteristics of the aquatic receiving environment

3.1 Kaituna River flow

Treated meatworks wastewater from AFFCO Plant Rangiuru is discharged into the Kaituna River. The Kaituna River is approximately 350 kilometres in length and carries water from Lakes Rotoiti and Rotorua to the sea at Maketu in the Bay of Plenty. In the upper 25 kilometres the river flows through a deep gorge in the ignimbrite plateau. Through this section the river drops 260 metres (m) and includes a number of water-falls and an incised gorge; it is fast flowing and turbulent. The remaining 28 km is slower, dropping another 20 m to the sea. The residence time over the whole river from lake to sea is relatively short not taking much longer than a day[1]. The AFFCO Rangiuru discharge

[1] AFFCO New Zealand Limited Assessment of Effects on the Environment Report

occurs immediately upstream of the identified “Lower Kaituna” sub-catchment, approximately 1.5 km upstream of the Te Matai hydrological station.

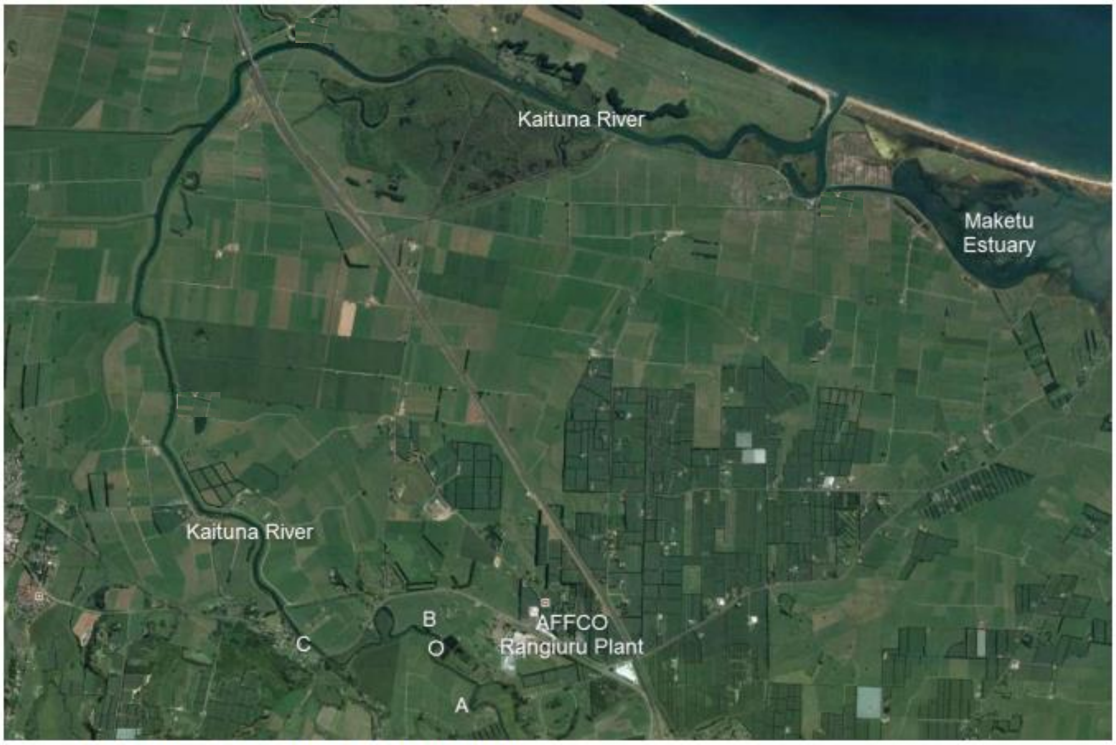

Figure 4 Map showing the AFFCO Rangiuru Plant (O), an upstream site (A), the compliance monitoring site 350m downstream of the discharge (B), Te Matai hydrological station ~1.5km downstream of the discharge

Available flow data collected between 2012 and 2017 for this site shows that flow ranged between 18.4 m^3/s and 122.1 m^3/s with an overall median of 32.9 m3/s. Summer median flows were however lower (30 m^3/s). On the average, river water to treated wastewater flow ratio is at least 1300 (i.e. 30/0.023)

Table 4. Descriptive summary of Kaituna River flow (Te Matai sampling station, 2012-2017)

	Flow (m3/s)	
Statistics	**2012-2017 (year-round)**	**2012-2017 (summer months only)**
Minimum	18.4	18.4
5th percentile	25.5	24.5
Median	32.9	30.0
75th percentile	40.4	34.5
95th percentile	57.5	54.1
Maximum	122.1	122.1

3.2 Compliance monitoring

Condition 9 (9.1-9.3) of the existing consent requires that AFFCO collect representative water samples from the Kaituna River at the edge of the mixing zone (deemed to be 350m downstream of the discharge outfall) and analyse for *E.coli* during the summer months. It is required that *E.coli* concentrations downstream of the discharge do not exceed 273 *E.coli* per 100mL.

Analysis of FIB compliance monitoring data for the site[2] immediately downstream of the discharge (350m) indicates that:

- Compliance in terms of proportions of samples below the 273 *E.coli* per 100mL has generally improved over the years. For instance, nearly 80% of samples collected in 2002 at the Kaituna River site downstream of the discharge exceeded 273 *E.coli* per 100mL, compared to more recent years where less than 20% exceedance was observed (with the exception of 2016, see Figure 5).
- In 2014 and 2015, compliance was highest (100%) as all the samples collected at the downstream site had below 273 *E.coli* per 100mL (Figure 5).
- There were additional observations of interest in the *E.coli* data collected at edge of the mixing zone site. For instance, *E.coli* concentrations downstream (200 CFU/100mL) were higher than those of the discharge (80 CFU/100mL) on 7/1/2016. Also, elevated *E.coli* concentrations downstream (7100 CFU/100mL) was observed on 18/2/2016 following heavy rainfall[3] (76.5 mm) on the sampling day and the day prior to sampling (10mm), indicating that other catchment sources are contributing to the effects observed downstream of the discharge during extreme precipitation events.

[2] weekly samples from the true right bank of the Kaituna River

[3] Metadata accompanying compliance monitoring dataset

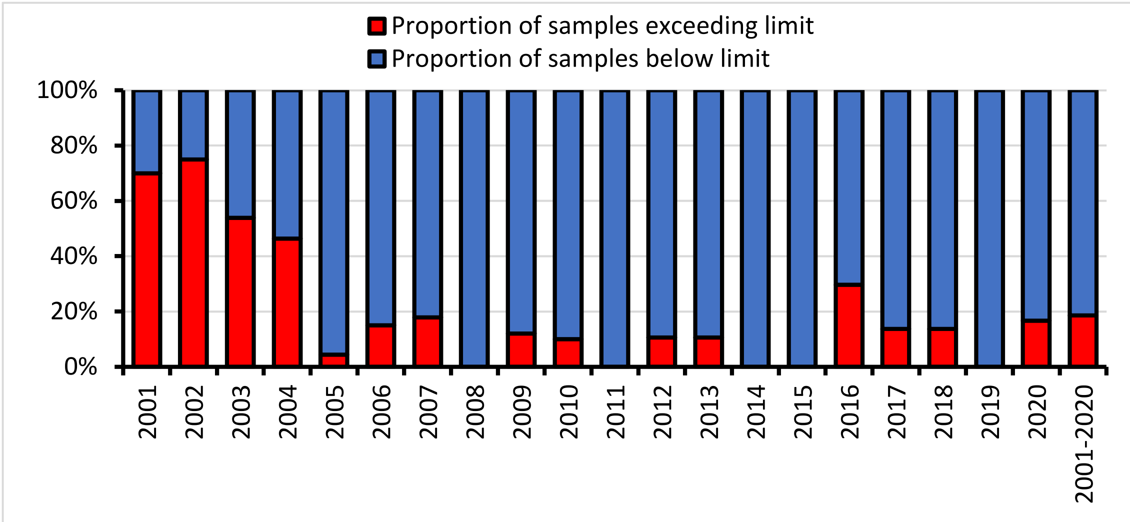

Figure 5 Compliance monitoring, 350m downstream of the discharge

4. Impact of wastewater discharge on faecal bacteria loadings in Kaituna River

In a mass balance modelling approach, treated wastewater concentrations of FIB (*E. coli and faecal coliform)* in AFFCO Plant wastewater were combined with FIB data for the receiving waterbody upstream of the discharge to predict how the discharged wastewater will affect the faecal bacteria load in the Kaituna river.

Projected concentrations of analytes following the wastewater discharge to the Mataura river were estimated as follows:

$$C_{FIB,FinalConc} = \frac{(C_{FIB,baseline} \cdot Q_{baseline}) + (C_{FIB,WW} \cdot Q_{WW})}{Q_{baseline} + Q_{WW}} \quad \text{Eqn. (1)}$$

where: $C_{FIB,FinalConc}$ is the daily projected concentration of *E.coli* and faecal coliform in the Kaituna Mataura River (expressed as CFU/100mL); $C_{FIB,baseline}$ is the baseline *E.coli* concentration (in the immediate upstream site on the river, i.e. no discharge of treated wastewater, expressed as CFU/100mL); $C_{FIB,WW}$, is the concentration of *E.coli* and faecal coliforms in the discharged AFFCO Plant wastewater expressed as CFU/100mL; Q_{WW} is the discharge of treated wastewater (expressed as m^3/s) and $Q_{baseline}$ is the discharge (flow rate) of the Kaituna River (expressed as m^3/s).

To cover seasonal variabilities that are typically associated with environmental data, distributions of these input parameters and Monte Carlo simulations were embedded in the mass balance calculations. This probabilistic modeling approach captures all scenarios from worst to best case, of wastewater flow rate, wastewater concentrations, receiving water flow rate and receiving water FIB concentrations. Details of input parameters applied in the Monte-Carlo-based mass balance dilution model are presented in Table 9.

This mass balance modelling approach assumes: 1) conservation of mass; 2) complete mixing, and; 3) that water quality measurements are accurate and representative.

Results from previous mixing studies have already shown that the treated wastewater is fully mixed at the site 350m downstream of the discharge. As the mass balance modelling approach typically assumes full mixing, it is an appropriate methodology to assess dilution at the site 350m downstream of the discharge and beyond. However, a mass balance modelling approach, by default, does not include considerations for partial mixing or the potential for the discharged wastewater to flow along the river edge or to accumulate along the riverbank within the mixing zone, depending on the hydrological and meteorological conditions. To address this issue of reduced dilution at the river edge within the mixing zone, we considered five additional dilution scenarios (i.e., 1%, 5%, 10%, 25% and 50% mixing; see Table 9) in the mass balance model. Consequently equation (1) was modified to:

$$C_{FIB,FinalConc} = \frac{(C_{FIB,baseline} \cdot Q_{baseline} \cdot RF) + (C_{FIB,WW} \cdot Q_{WW})}{Q_{baseline} \cdot RF + Q_{WW}} \qquad \text{Eqn. (1)}$$

where RF is a reduction factor (0.5, 0.25, 0.1, 0.05 or 0.01) incorporated to reduce the amount of Kaituna River water available to dilute the AFFCO Plant discharge by 50%, 75%, 90%, 95% and 99%, respectively, for the 50%, 25%, 10%, 5% and 1% mixing scenarios.

Predicted concentrations downstream, after dilution of the treated wastewater discharge were thereafter assessed against relevant water quality guidelines for recreational waters (NPSFM 2017, MoH 2003) to comment on the likely effects on recreational activities downstream of the discharge.

The National Policy Statement for Freshwater Management 2017 (updated 2020) (see Table 5) sets out the objectives and policies for freshwater management under the Resource Management Act 1991. According to the NPS-FM, to assess swimmability, four metrics are considered: % exceedance of 540 *E. coli* /100 mL; median *E. coli* /100 mL; 95th %tile *E. coli* /100 mL; and % exceedance of 260 *E. coli* /100 mL. This combination of metrics enables councils to provide a clearer picture about the nature of progress towards *E. coli* targets for any particular monitored river reach and gives greater assurance when moving between attribute states than would be obtained by using the median and 95th percentile statistics alone.

Table 5 NPS-FM Attribute States and corresponding thresholds for most* freshwater sites (as stated in Table 9 NPS-FM 2020)

Value	Human health for recreation			
Freshwater Type	Rivers, general			
	Numeric Attribute State			
Attribute band	% Exceedance over 540 cfu/100 mL	% Exceedances over 260 cfu/100 mL	Median concentration (cfu/100 mL)	95th percentile of E. coli/100mL
A (Blue)	<5%	<20%	≤130	≤540
B (Green)	5-10%	20-30%	≤130	≤1000
C (Yellow)	10-20%	20-34%	≤130	≤1200
D (Orange)	20-30%	>34%	>130	>1200
E (Red)	>30%	>50%	>260	>1200

*excluding primary contact sites (i.e. designated swimming sites)

We note that in the revised NPS-FM (2020) policy document, a separate array of attribute states, thresholds and a national bottom line is presented for "primary contact sites" (i.e. designated swimming sites), and specifically for bathing seasons. Based on this consideration, primary contact sites are graded excellent, good, fair and poor (see Table 6).

Table 6 NPS-FM "Attribute Units" and corresponding thresholds (as stated in Table 22 NPS-FM 2020)

Value	**Human health for recreation (during bathing season)**
Freshwater Body Type	Rivers, designated primary contact sites
	Numeric Attribute State
Attribute band	95th percentile of E. coli/100mL
Excellent	≤130
Good	>130 and ≤260
Fair	>260 and ≤540
National bottom line	540
Poor	>540

The MfE/MoH guidelines use a combination of a risk grading of the catchment, supported by the direct measurement of appropriate faecal indicators to assess the suitability of a site for recreation in a Microbiological Assessment Category (MAC)-based system (Table 7). In addition, alert and action guideline levels are used for surveillance throughout the bathing season (Table 8).

Table 7. Microbiological Assessment Category definitions for marine waters set out in the MfE/MoH policy document.

Microbiological Assessment Category (MAC)	Threshold	Implication*
A	Sample 95 percentile ≤ 40 enterococci/100 mL	"Very good" to "Follow up"
B	Sample 95 percentile 41–200 enterococci/100 mL	"Very good" to "Follow up"
C	Sample 95 percentile 201–500 enterococci/100 mL	"Follow up" to "Very Poor"
D	Sample 95 percentile > 500 enterococci/100 mL	"Follow up" to "Very Poor"

*depending on the results of sanitary inspection

Table 8. 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.

Table 9 Table of inputs: mass balance dilution model

Scenario	Parameter	Value	Comments/ Distribution applied
All seasons	Kaituna River flow (cumecs)	min=18.4, 5th perc = 25.49, median =32.94, 95th perc = 57.53, max = 122.1	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on BoPRC data collected at Te Matai (2012-2017)
	AFFCO Ranguiu (cumecs)	min=0.0, 5th perc = 0.001, median =0.019, 95th perc = 0.047, max =0.111	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on AFFCO monitoring data (2015-2020)
	Kaituna River Upstream FIB (CFU/100mL)	E.coli, min=0.0, 5th perc = 11, median =33, 95th perc = 236, max =1600 Faecal coliform = 0 Enterococci = 94	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on BoPRC data collected at a far upstream site, Maungarang Road (1991-2020) because there is no data for FIB immediately upstream of the discharge. There is no upstream data for faecal coliform that captures variabilities over time. Hence incremental risk as a result of the discharge was assessed.
	AFFCO Ranguiu FIB (CFU/100mL)	Monitoring data (E.coli, 2015-2020), min=2, 5th perc = 28, median =300, 95th perc = 2920, max = 20,000 Monitoring data (Enterococci, 2015-2020), min=2, 5th perc = 13, median =285, 95th perc = 4760, max = 16000	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on AFFCO monitoring data (2015-2020).
Summer only	Kaituna River flow (cumecs)	min=18.4, 5th perc = 25.49, median =30, 95th perc = 54.1, max = 122.1	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on BoPRC data collected at Te Matai (2012-2017)
	AFFCO Ranguiu (cumecs)	min=0.0, 5th perc = 0.002, median =0.023, 95th perc = 0.030, max =0.111	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on AFFCO monitoring data (2015-2020)
	Kaituna River Upstream FIB (CFU/100mL)	E.coli, min=0.0, 5th perc =5, median =25, 95th perc = 240, max =5400 Faecal coliform = 0 Enterococci = 94	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on BoPRC data collected at an upstream site, Maungarang Road (1991-2020) There is no upstream data for faecal coliform that captures variabilities over time. Hence incremental risk as a result of the discharge was assessed.
	AFFCO Ranguiu FIB (CFU/100mL)	Monitoring data (*E.coli* , months, 2015-2020), min=2, 5th perc = 96, median =550, 95th perc = 4295, max = 20000 Monitoring data (Enterococci, 2015-2020), min=2, 5th perc = 13, median =285, 95th perc = 4760, max = 16000	RiskPearson5 (5th perc, median, 95th perc), truncated at min and max. Based on AFFCO monitoring data (2015-2020).

Table 10 Mixing scenarios considered in the mass balance modelling

Location in Kaituna River	**Scenario**	**Considered level of mixing in zone**
Within 350m downstream of discharge	Inside the mixing zone	1% mixing
	Inside the mixing zone	5% mixing
	Inside the mixing zone	10% mixing
	Inside the mixing zone	25% mixing
	Inside the mixing zone	50% mixing
Beyond 350m downstream of discharge	Outside the mixing zone	100% mixing

We note that the NPS-FM guidance document requires water quality assessment to be based on all data collected within at least a 5-year period and regardless of the season. Given the possibility of low flows in summer, the modelling was also repeated for summer months. This approach is considered more stringent given that the focus is on the low flow months and periods when there is a high probability of contact recreation in the Kaituna River.

4.1 Dilution achieved in the receiving environment

Results of the mass balance modelling provided insights on the dilutions that would typically occur following the discharge of treated wastewater into the Kaituna River. The AFFCO Plant wastewater discharge flow rate (median =0.019 m^3/s, see Table 9) is just a small fraction of the discharge at the Kaituna River (median =32.94 m^3/s, see Table 9).

Outside the mixing zone where 100% of dilution is achieved, mass balance modelling predicts that 50 percent of the time, the AFFCO Plant discharge will be diluted 1,322-folds in summer and 1,755-folds at other times of the year (see 50th perc in Figure 6, Figure 7 n-and Table 11).

Within the mixing zone, varying lower levels of dilution is achieved. For instance, it is predicted that, if 50% dilution is achieved, 50 percent of the time, the AFFCO Plant discharge will be diluted by 661-folds in summer and 878-folds at other times of the year (see 50th perc in Figure 6, Figure 7 n-and Table 11).

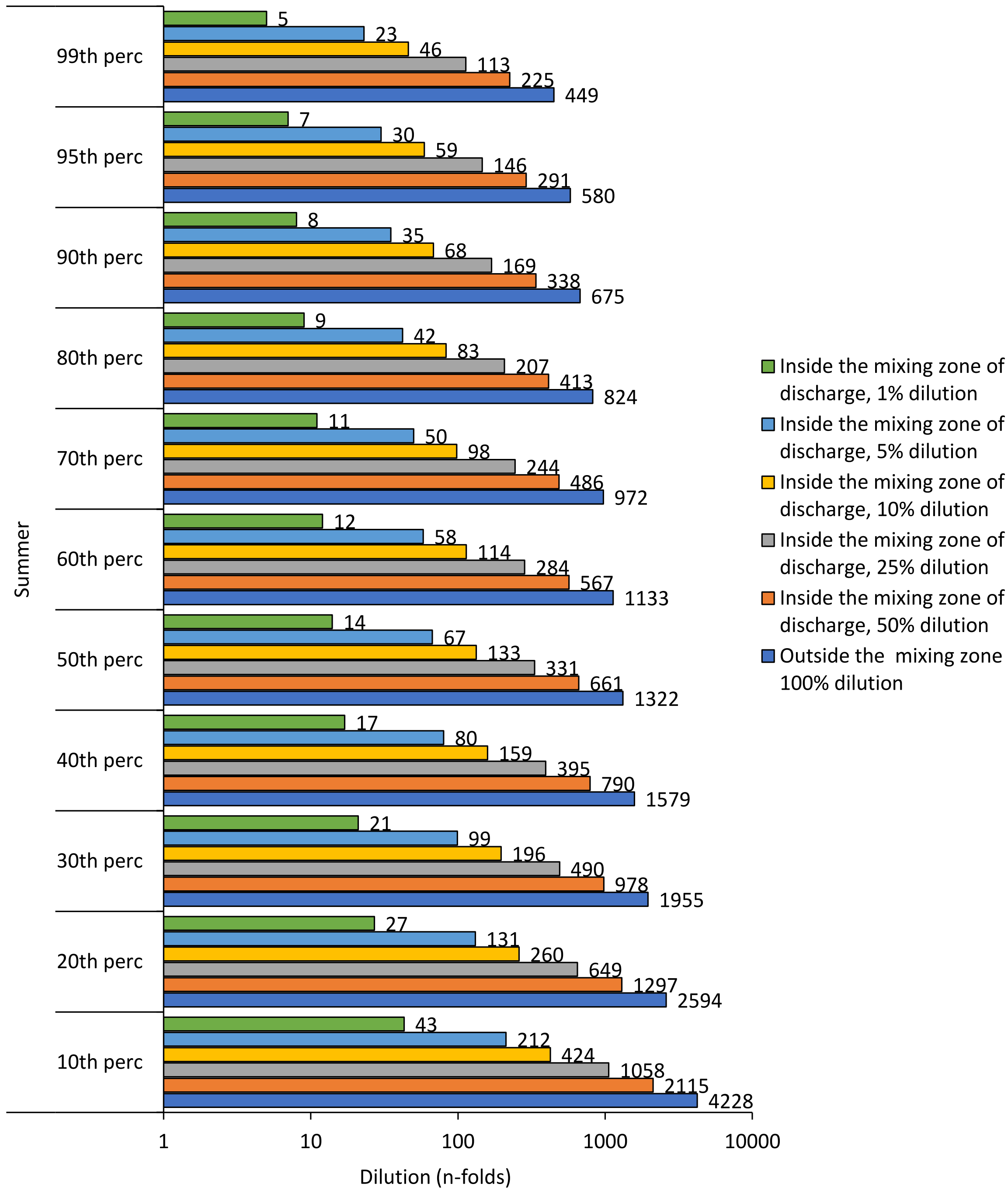

Figure 6 Dilutions achieved in the receiving environment (summer) following discharge of AFFCO Rangiuru Plant treated wastewater.

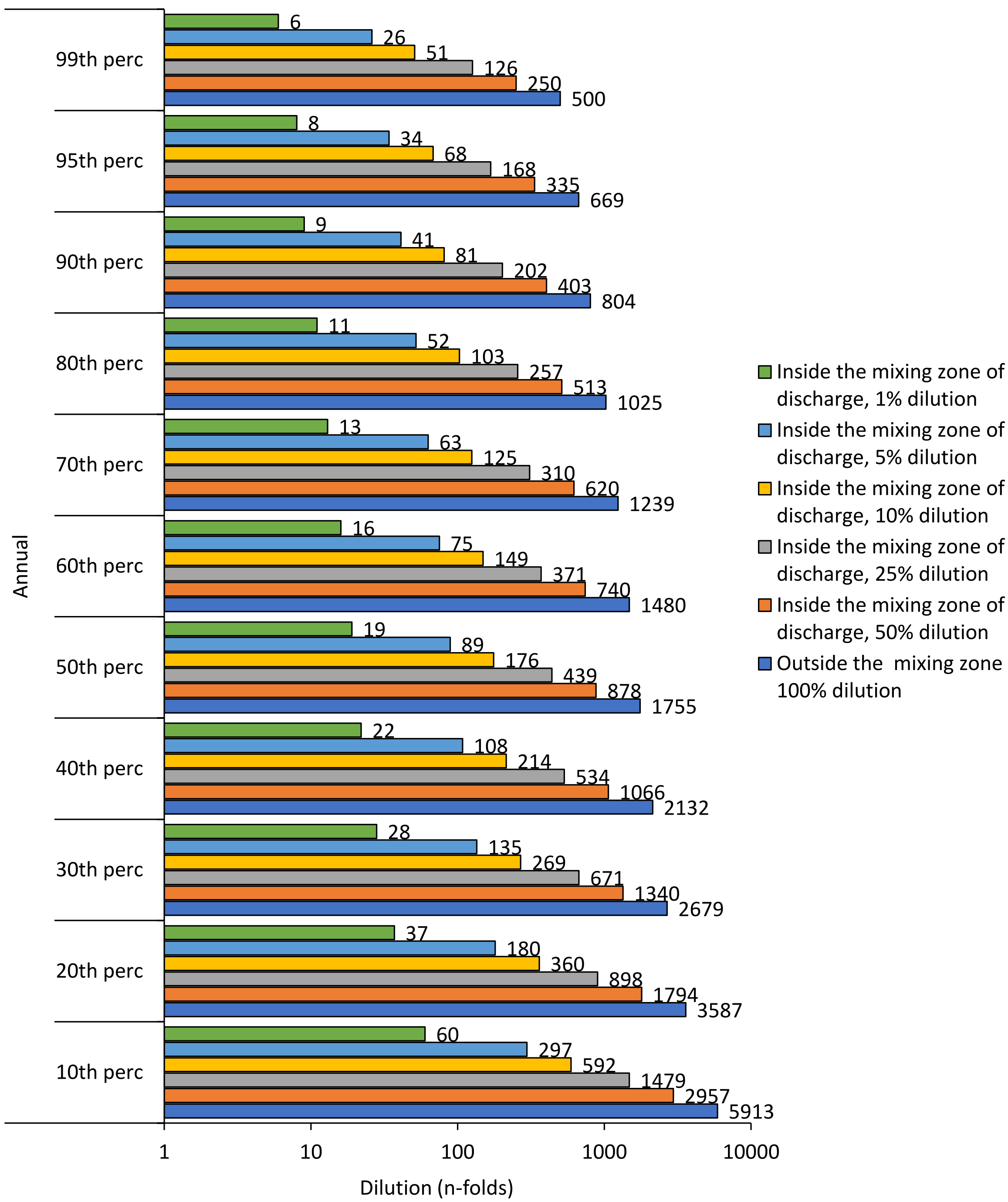

Figure 7 Dilutions achieved in the receiving environment (annual) following discharge of AFFCO Rangiuru Plant treated wastewater.

Table 11. Effective (a) summer and (b) annual dilution of AFFCO Rangiuru Plant discharge achieved in the receiving environment. (dilution expressed in n-folds)

		Outside the mixing zone	Inside the mixing zone of discharge				
Season	**Scenario**	**100% dilution**	**50% dilution**	**25% dilution**	**10% dilution**	**5% dilution**	**1% dilution**
Annual	10th perc	5913	2957	1479	592	297	60
	20th perc	3587	1794	898	360	180	37
	30th perc	2679	1340	671	269	135	28
	40th perc	2132	1066	534	214	108	22
	50th perc	1755	878	439	176	89	19
	60th perc	1480	740	371	149	75	16
	70th perc	1239	620	310	125	63	13
	80th perc	1025	513	257	103	52	11
	90th perc	804	403	202	81	41	9
	95th perc	669	335	168	68	34	8
	99th perc	500	250	126	51	26	6
Summer	10th perc	4228	2115	1058	424	212	43
	20th perc	2594	1297	649	260	131	27
	30th perc	1955	978	490	196	99	21
	40th perc	1579	790	395	159	80	17
	50th perc	1322	661	331	133	67	14
	60th perc	1133	567	284	114	58	12
	70th perc	972	486	244	98	50	11
	80th perc	824	413	207	83	42	9
	90th perc	675	338	169	68	35	8
	95th perc	580	291	146	59	30	7
	99th perc	449	225	113	46	23	5

4.2 Effect on *E.coli* attribute state in relation to contact recreation

The results of predicted *E.coli* concentrations obtained following mass balance dilution modeling of AFFCO Rangiuru Plant wastewater *E.coli* loading in an NPS-FM context are presented in Table 12.

Without the discharge (i.e. upstream of the discharge), E. coli concentrations in the Kaituna River are within the range associated with the best attribute state, i.e. Attribute State A (Blue) depicting very low risk of infection for contact recreation, see Table 12).

Following the AFFCO Rangiuru Plant discharge, different NPS-FM statistics are predicted depending on the level of dilution achieved in the receiving environment.

Within the mixing zone.

- If 50% dilution[4] of the AFFCO Plant discharge is achieved in the receiving environment, mass balance modelling results predict that:
    - the proportion of samples with *E.coli* levels over 540 CFU/100mL and over 260 CFU/100mL will remain the same (Table 12).
    - median and 95th percentile *E.coli* concentrations in the Kaituna River will increase marginally by a maximum of 2CFU/100mL, regardless of the season (Table 12).
    - The attribute state of the Kaituna River will remain Blue (State A).

[4] i.e. 50% of the full mixing

Table 12 Annual and summer impact of AFFCO Rangiuru Plant discharge on Kaituna River *E.coli* Attribute State

Discharge Scenario	Location on Kaituna River	Mixing Scenario	% Exceedance over 540 cfu/100 mL	% exceedances over 260 cfu/100 mL	Median concentration (cfu/100 mL)	95^{th} percentile of E. coli/100mL	NPS-FM Attribute State
Annual	Upstream of discharge	no discharge	2%	4%	25	236	Blue (A)
	Inside the mixing zone (within 350m downstream of discharge)	1% dilution	3%	8%	52	375	Blue (A)
		5% dilution	2%	5%	33	256	Blue (A)
		10% dilution	2%	5%	29	243	Blue (A)
		25% dilution	2%	4%	27	236	Blue (A)
		50% dilution	2%	4%	26	236	Blue (A)
	Outside the mixing zone (beyond 350m downstream of discharge)	100% dilution	2%	4%	25	236	Blue (A)
Summer	Upstream of discharge	no discharge	2%	4%	25	236	Blue (A)
	Inside the mixing zone (within 350m downstream of discharge)	1% dilution	4%	12%	77	492	Blue (A)
		5% dilution	2%	5%	40	270	Blue (A)
		10% dilution	2%	5%	34	248	Blue (A)
		25% dilution	2%	5%	29	241	Blue (A)
		50% dilution	2%	4%	27	238	Blue (A)
	Outside the mixing zone (beyond 350m downstream of discharge)	100% dilution	2%	4%	26	236	Blue (A)

*attribute state is based on the 2020 NPS FM Table 9 thresholds for sites on the river in which there may be human contact but is not designated as a swimming spot or primary contact site

- If 25% dilution is achieved,
    - The proportion of samples with *E.coli* concentrations over 540 CFU/100mL will remain the same (Table 12).
    - The proportion of samples with *E.coli* concentrations over 260 CFU/100mL will slightly increase (+1).
    - The median and 95th percentile *E.coli* concentrations in the Kaituna River will increase marginally by a maximum of 5 CFU/100mL, regardless of the season (Table 12).
    - The attribute state of the Kaituna River will remain Blue (State A).
- If 10% dilution is achieved,
    - The proportion of samples with *E.coli* concentrations over 540 CFU/100mL will remain the same (Table 12).
    - The proportion of samples with *E.coli* concentrations over 260 CFU/100mL will slightly increase (+1).
    - The median and 95th percentile *E.coli* concentrations in the Kaituna River will increase marginally by a maximum of 12 CFU/100mL (Table 12).
    - The attribute state of the Kaituna River will remain Blue (State A).
- If 1% dilution is achieved,
    - The proportion of samples with *E.coli* concentrations over 540 CFU/100mL will slightly increase (+2).
    - The proportion of samples with *E.coli* concentrations over 260 CFU/100mL will markedly increase (for instance, from 4% to 12% in summer months, see Table 12).
    - The median *E.coli* concentrations in the Kaituna River will increase markedly (25 CFU/100mL to 77 CFU/100mL in summer months.
    - The 95th percentile *E.coli* concentrations increase significantly from 235 CFU/100mL to 492 CFU/100mL during summer months (Table 12).
    - However, the attribute state of the Kaituna River will still remain Blue (State A) as NPS-FM statistics are only pushed to (but do not exceed) the borderline for Attribute State A waters (Table 12)

<u>Outside the mixing zone</u>

- Outside the mixing zone where a 100% dilution of AFFCO Rangiuru Plant wastewater is achieved**,** mass balance modelling predicts
    - No major changes in NPS-FM statistics or attribute state (Table 12) during the annual and summer scenarios.
    - 95th percentile *E.coli* concentrations as well as the proportion of samples with *E.coli* over 540 CFU/100mL and over 260 CFU/100mL will remain the same (Table 12).
    - The median *E.coli* concentrations in the Kaituna River will only increase marginally (+1 CFU/100mL) during summer months (Table 12).
    - The attribute state of the Kaituna River will remain Blue (State A).

Results of mass balance modelling shows that the release of treated animal works wastewater produced by AFFCO Plant Rangiuru does not increase the *E. coli* concentrations in the receiving Kaituna River water to the extent that it causes an NPS-FM attribute state change, even during the worst-case scenario of reduced dilution at the river banks within the mixing zone. In terms of swimmability from an NPS-FM perspective, these results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge on the Kaituna River is **not more than minor.**

However, care needs to be taken when interpreting the results in an NPS-FM context because of the following reasons.

- The NPS-FM-Table-9 thresholds tells little or nothing in relation to risks associated with zoonotic pathogens other than Campylobacter. Also, the thresholds are based on microbiological data collected nationally nearly 20 years ago when the MfE/MoH water quality guidelines were being formulated. These concerns have already been raised in submissions to the Ministry for the Environment (Dada 2017) and a more recent epidemiological study has now been commissioned to update these numbers (ESR 2019[5]).
- In an NPS-FM-Table-9 context it is difficult to know whether huge increases in the *E.coli* concentrations within the same band infer increased risks of exposure to zoonotic pathogens. For instance, if only a 1% dilution occurs, as may be the case within the mixing zone, the 95th percentile concentration increases markedly from 236 to 492 CFU/100mL, albeit within the same Band A.
- As acknowledged in the MfE/MoH guidelines, wastewater treatment technologies tend to alter correlations between FIB and the pathogens they are meant to be proxies for. Hence, applying the NPS-FM-Table-9 standard to assess a site receiving point discharges of treated wastewater may present a false outlook in terms of risk assessment. This necessitates the need for other methods of risk assessment and particularly relevant is the quantitative microbial risk assessment approach which uses dose-response functions of specific zoonotic pathogens and the amounts of water individuals ingest during contact recreation to make a more definitive risk assessment (see Section 5).

It is important to note that when evaluating these results, consideration should be given to the absence of recreational activity (swimming) in the Kaituna River for a distance of 1,500 m downstream from the discharge point. As previous mixing studies have established that the wastewater is fully mixed (100% dilution) at the 350m mark, we also assessed the effect of a fully mixed treated wastewater on Te Matai road bridge site, the designated swimming site 1,500 m downstream from the discharge point. The site already has 95th percentile E.coli concentrations classifiable as being of "poor" status based on the NPS-FM thresholds for contact recreation sites. Mass balance modelling show that the discharge does not increase the 95th percentile observable at this site, these results indicate

[5] https://www.esr.cri.nz/home/about-esr/media-releases/pilot-survey/

that the effect of the AFFCO Rangiuru Plant meatworks discharge on the Te Matai road bridge site *E.coli* is **not more than minor.**

Table 13 Annual and summer impact of AFFCO Rangiuru Plant discharge on Te Matai road bridge site *E.coli* Attribute State*.

Discharge Scenario	Location on Kaituna River	Mixing Scenario	95th percentile of E. coli/100mL	NPS-FM Attribute State
Summer	Upstream of discharge**	no discharge	1775	Poor
	Te Matai road bridge (1,500 m downstream of discharge)	100% dilution, after discharge	1775	Poor

*attribute state is based on the 2020 NPS FM Table 22 thresholds for sites on the river which there may be human contact and are designated as a swimming spot or primary contact site. This site is regularly used or would be regularly used for recreational activities.
** E.coli concentrations for Matai road bridge used because there is no designated swimming site upstream of the discharge.

4.3 Effect on FIB in relation to raw shellfish consumption

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[6] (New Zealand Food Safety Authority (NZFSA), 2006). These guidelines are based on shellfish tissues and can be applied to point source-affected approved growing areas where 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, two criteria need to be met:

- The median FC content of samples taken over a shellfish-gathering season shall not exceed an MPN of 14/100 mL, and;

[6] 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

- 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.

There are no faecal coliform data for the Kaituna River site upstream of the discharge. The only faecal coliform data were available was for a single sampling conducted in Feb 2016 (faecal coliform concentration = 120 CFU/100mL), as reported in the Assessment of Effects Report Table 10.

Since the faecal coliform standards are based on percentiles (50th percentiles and 90th percentiles), the single upstream faecal coliform concentration of 120 CFU/100mL cannot be used to assess the effect of the discharge on the microbiological quality of potentially shellfish harvesting waters. To address the issue of lack of variability in the upstream faecal coliform data, an incremental risk approach was therefore used in the mass balance modelling to assess the impact of the discharge in relation to shellfish. This approach assumed that the receiving water baseline faecal coliform concentration was equal to zero (i.e. 0 CFU/100mL) and increases following dilution with the discharge. These values were compared with standards for shellfish gathering waters. Predicted final concentrations are presented in Table 14.

Within the mixing zone (within 350m downstream of discharge)

- If at least 5% dilution of the AFFCO Plant discharge is achieved in the receiving environment, mass balance modelling predicts that:
    - the median faecal coliform concentration in the receiving water will not exceed 14 CFU/100mL, and,
    - not more than 10% of samples will exceed 43 faecal coliforms per 100 mL
    - the two criteria for satisfactory water quality for shellfish harvesting purposes will therefore be satisfied.
- If 1% dilution is achieved,
    - the median faecal coliform concentration in the receiving water is predicted to be as high as 17 faecal coliforms per 100mL during summer (Table 14).
    - Up to 20% of the samples will have faecal coliform concentrations higher than 47 cells per 100mL.
    - the two criteria for satisfactory water quality for shellfish harvesting purposes will not be satisfied.

Table 14 Effect of the AFFCO Rangiuru discharge on the quality of Kaituna River (in terms of shellfish harvesting)

Discharge Scenario	Location on Kaituna River	Mixing scenario	10th Perc.	50th Perc.	70th Perc.	80th Perc.	90th Perc.	95th Perc.	99th Perc.
Annual	Inside the mixing zone	no discharge	0	0	0	0	0	0	0
	Inside the mixing zone	1% dilution	3	13	25	37	70	127	309
	Inside the mixing zone	5% dilution	1	3	5	8	15	27	67
	Inside the mixing zone	10% dilution	0	1	3	4	8	14	34
	Inside the mixing zone	25% dilution	0	1	1	2	3	5	14
	Inside the mixing zone	50% dilution	0	0	1	1	2	3	7
	Outside the mixing zone	100% dilution	0	0	0	0	1	1	3
Summer	Inside the mixing zone	no discharge	0	0	0	0	0	0	0
	Inside the mixing zone	1% dilution	4	17	30	47	87	156	386
	Inside the mixing zone	5% dilution	1	4	7	10	19	34	83
	Inside the mixing zone	10% dilution	0	2	3	5	9	17	42
	Inside the mixing zone	25% dilution	0	1	1	2	4	7	17
	Inside the mixing zone	50% dilution	0	0	1	1	2	3	8
	Outside the mixing zone	100% dilution	0	0	0	1	1	2	4

<u>Outside the mixing zone (beyond 350m downstream of discharge)</u>

- Outside the mixing zone where a 100% dilution of AFFCO Rangiuru Plant wastewater is achieved**,** mass balance modelling predicts that:
  - the median faecal coliform concentration in the receiving water attributable to the discharge will be 0 CFU/100mL, regardless of the time of the year. It therefore does not exceed 14 CFU/100mL, and satisfies the first criterion for satisfactory water quality for shellfish harvesting purposes
  - 99% of the time the faecal coliform concentration in the receiving water attributable to the discharge will be less than 4 CFU/100mL. It thus satisfies the second criterion for satisfactory water quality for shellfish harvesting purposes

Outside the mixing zone, the results of mass balance modelling shows that the release of treated animal works wastewater produced by AFFCO Plant Rangiuru does not increase the faecal coliform concentrations in the receiving Kaituna River water to the extent that it affects the quality of water available for shellfish harvesting purposes. <u>These results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge on the Kaituna River is **not more than minor.**</u>

Within the mixing zone, the effect of the AFFCO Plant Rangiuru wastewater on the quality of shellfish harvesting water is dependent on the level of dilution achieved. If exceptionally low dilution (e.g. 1% dilution) is achieved in the receiving environment, the discharge is predicted to have more than a minor effect. No observable effect in terms of faecal coliform concentration is seen if at least 5% dilution is achieved.

However, care needs to be taken when interpreting these results because of the filter feeding nature of shellfishes. Shellfishes can take up pathogens directly from the water column and accumulate these over time such that the accumulated pathogens can be present within 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, Dada 2020).

Applying this context to the results presented in Table 14, if a 25% dilution of the AFFCO Plant discharge is achieved in the receiving environment, mass balance modelling predicts that the median faecal coliform concentration in the receiving water will only increase by 1 CFU/100mL, and hence satisfies the first criterion for satisfactory water quality for shellfish harvesting purposes (as it is less than 14 CFU/100mL). A concern based on the filter feeding nature of shellfishes, is that an increase of +1 CFU/100mL of faecal coliforms in the water column may translate into hundred-fold higher concentrations in the shellfish tissues. Hence, the ideal approach to examining health risks in relation to shellfish microbiological quality is a QMRA approach that incorporates dose response functions for zoonotic pathogens that could be accumulated in the tissues of the shellfish, bioaccumulation factors and the amount of raw shellfish consumed in a single meal (see Section 5).

4.4 Effect on Enterococcus loading

Enterococci are the ideal FIB when assessing swimmability in marine waters. It is important to note that the receiving water environment is a freshwater site and not a marine site, although we acknowledge that the river empties into a marine environment approximately 14 km downstream. There are also tidal effects, as reflected in the saltwater wedge, which only extends as far upstream as the Bay of Plenty Regional Council flow gauge located at Te Mata, several kilometres downstream of the discharge. Water quality monitoring at the discharge and below has confirmed there is no saltwater intrusion. The use of enterococci is thus for context purposes.

Without the discharge, enterococci concentration for the Kaituna River site upstream of the discharge is 94 CFU/100mL, based on the simple sampling conducted in Feb 2016, as reported in the Assessment of Effects Report Table 10.

Predicted final concentrations following dilution of the AFFCO Plant discharge are presented in Table 14.

Within the mixing zone (within 350m downstream of discharge)

- If 50% dilution of the AFFCO Plant discharge is achieved in the receiving environment, mass balance modelling results predicts that:
  - The proportion of samples with enterococci over 140 CFU/100mL will remain the same (Table 15).
  - The 95th percentile enterococci concentrations in the Kaituna River will increase marginally by a maximum of 6 CFU/100mL in summer (Table 15).
  - The Microbiological Assessment Category (MAC) of the Kaituna River will not change, i.e. remain B (Table 15).
- If 25% dilution is achieved, mass balance modelling results predicts that:
  - the proportion of samples with enterococci over 140 CFU/100mL will increase by 1% (Table 15).
  - The 95th percentile enterococci concentrations in the Kaituna River will increase marginally by a maximum of 11 CFU/100mL in summer (Table 15).
  - The Microbiological Assessment Category (MAC) of the Kaituna River will not change, i.e. it will remain B (Table 15).
- If 5% dilution is achieved,
  - The proportion of samples with enterococci over 140 CFU/100mL will increase by 6% (Table 15).
  - The 95th percentile enterococci concentrations in the Kaituna River will increase by 56 CFU/100mL in summer (Table 15).

- The Microbiological Assessment Category (MAC) of the Kaituna River will not change, i.e. it will remain B (Table 15).

- If 1% dilution is achieved,
    - The proportion of samples with enterococci over 140 CFU/100mL will increase by 24% (Table 15).
    - The 95th percentile enterococci concentrations in the Kaituna River will increase by 260 CFU/100mL in summer (Table 15).
    - The Microbiological Assessment Category (MAC) of the Kaituna River will change from B to a poorer state, C (Table 15).

<u>Outside the mixing zone (beyond 350m downstream of discharge)</u>

- If 100% dilution of the AFFCO Plant discharge is achieved in the receiving environment, mass balance modelling results predicts that:
    - The proportion of samples with enterococci over 140 CFU/100mL will remain the same (Table 15).
    - The 95th percentile enterococci concentrations in the Kaituna River will increase marginally by a maximum of 3 CFU/100mL in summer (Table 15).
    - The Microbiological Assessment Category (MAC) of the Kaituna River will not change, i.e. it will remain B (Table 15).

However, care needs to be taken when interpreting these enterococci results. First, the most realistic scenario in the receiving environment, in the case of marine water quality assessment is the 100% dilution scenario. Also, marine water only becomes applicable several kilometres downstream of the discharge. Secondly, because the MfE/MoH guideline document categorically states that these guidelines are expected to be applied in conjunction with a sanitary survey, it is difficult to interpret changes in these enterococci concentration from a health risk perspective. For instance, a marine water body classified as MAC Class A may have a variety of meanings, ranging from “very good” to “follow up” depending on the results of sanitary inspections, which are invariably subjective. QMRA is a more robust approach to examining health risks in relation to suitability for recreational purposes as it focuses on specific pathogens that may be present in the water (see Section 0).

Table 15 Effect of the AFFCO Rangiuru Plant discharge on marine water quality in the Kaituna River

Discharge Scenario	Location on Kaituna River	Mixing scenario	Proportion of samples with enterococci above 140 CFU/100mL	95th Percentile Enterococci concentration (CFU/100mL)	MAC
Annual	Inside the mixing zone	no discharge	0%	94	B
	Inside the mixing zone	1% dilution	21%	303	C
	Inside the mixing zone	5% dilution	5%	139	B

	Inside the mixing zone	10% dilution	2%	117	B
	Inside the mixing zone	25% dilution	0%	103	B
	Inside the mixing zone	50% dilution	0%	99	B
	Outside the mixing zone	100% dilution	0%	96	B
Summer	Inside the mixing zone	no discharge	0%	94	B
	Inside the mixing zone	1% dilution	24%	354	C
	Inside the mixing zone	5% dilution	6%	150	B
	Inside the mixing zone	10% dilution	3%	122	B
	Inside the mixing zone	25% dilution	1%	105	B
	Inside the mixing zone	50% dilution	0%	100	B
	Outside the mixing zone	100% dilution	0%	97	B

5. Quantitative Microbial Risk Assessment (QMRA)

5.1 Overview

Quantitative microbial risk assessment (QMRA) is a framework that applies information and data incorporated into mathematical models that predict the health risk from pathogens through environmental exposures and characterize the nature of any adverse outcomes. Although several QMRAs have been documented for human waste discharge into receiving waters in New Zealand, QMRA studies that assess the effect of discharge from animal factory wastewater discharge are few (e.g. see Dada 2019). As argued in Section 4, QMRA with a focus on animal factory wastewater thus provides a scientifically defensible mechanism to characterize risks from animal-based wastewater. This QMRA employs peer-reviewed microbial risk assessment tools and approaches (USEPA, 2010).

Typically, four steps are involved in a QMRA (Haas, Rose, & Gerba, 1999a):

- hazard identification;
- exposure assessment;
- dose-response analysis, and;
- risk characterization.

5.2 Hazard analysis

Wastewater from the AFFCO Plant can pose potential risks to human health if the wastes are not adequately treated or contained. In line with published literature, the most critical zoonotic microbial groups in terms of public health risk from such wastewaters are bacteria and protozoans (Courault et al., 2017; Prevost et al., 2015). A selection of these zoonotic pathogens [7] in the AAFCO Plant wastewater was made for this QMRA based on the following considerations:

Campylobacter:

- *Campylobacter* spp. are prevalent in livestock, particularly poultry and sheep.
- Several dose-response relationships for *C. jejuni* have been published (Medema, Teunis, Havelaar, & Haas, 1996; Teunis et al., 2005; USEPA, 2010).

E. coli O157:H7

- It is representative of Shiga toxin-producing *E. coli* (STEC), which potentially causes serious adverse health outcomes, and has been implicated in waterborne outbreaks.
- It is frequently isolated from cattle manure, often in very high densities
- It can potentially grow in soil, sediment, water, and possibly other environmental matrices—all of which emphasize its potential to be found in animal factory wastewater-impacted waters (USEPA, 2010).

Salmonella

- It is very heterogeneous as its serotypes have adapted to a wide variety of host-specific environments including humans.
- It can persist in environmental median for up to 180 days or longer (Holley, Arrus, Ominski, Tenuta, & Blank, 2006).
- *Salmonella* can be detected throughout the year, with densities and serotype diversity typically higher during summer months than winter months (Haley, Cole, & Lipp, 2009).

Cryptosporidium and *Giardia* spp.

- These species have been implicated in many waterborne disease outbreaks both in New Zealand and globally
- Dose-response models are available for both protozoa, and both parasites can infect a significant proportion of the exposed population at low doses (Medema et al., 1996; Teunis et al., 2005; USEPA, 2010).
- *Cryptosporidium* and *Giardia* spp. are frequently isolated from livestock manure, and their respective oocysts and cysts can survive for extended periods of time in the environment (USEPA, 2010).

Other zoonotic pathogens.

- Other pathogens were also considered for inclusion as reference pathogens in the QMRA (e.g., *Listeria monocytogenes*, or *Leptospira*). However, these

[7] i.e. reference pathogens in the QMRA context

pathogens do not have available dose-response relationships based on human data (USEPA, 2010).

5.3 Exposure Assessment

Exposure assessment involves identification of populations that could be affected by pathogens. The main individuals at risk of exposure to pathogens from the Rangiuru Plant wastewater discharge are those who use Kaituna River sites potentially impacted by this discharge for contact recreation and those who consume raw shellfish harvested from these sites. To assess the potential level of exposure, the following considerations were incorporated into the QMRA:

- proximity of site to the discharge (i.e. at the compliance site 350m downstream of the AFFCO discharge where 100% mixing has been established to occur and within the mixing zone where a range of dilutions (1%, 5%, 10%, 25% and 50%) may potentially occur.
- the possible exposure pathways that allow the pathogen to reach people and cause infection (e.g. through ingesting polluted water);
- range (minimum, maximum and median) of zoonotic pathogen concentrations in treated wastewater;
- discharge volumes of the treated wastewater
- dilution potentials in the receiving water
- quantity of water ingested by a child/adult over a period of time during a particular recreational activity;
- quantity of raw shellfish harvested at the receiving environment and ingested by an individual in a single meal;
- estimation of the amount, frequency of exposure, and doses for an exposure.

AFFCO treated wastewater pathogen concentrations

Wastewater concentrations used in this QMRA were based on laboratory-analysed monitoring data collected at the AFFCO Plant. To adequately estimate potential health risk, it is important to estimate the proportion of human-infectious strains of each reference pathogen in each animal source. In this QMRA, a very conservative approach was applied, which assumed that all strains of each reference pathogen from the animal wastewater were human-infectious strains. Pathogen concentrations fed into the model were based on treated wastewater monitoring conducted between 2015 and 2017 (Table 16).

Predicting exposure doses

Typically, the dose of the pathogen that an individual ingests, inhales or comes into contact with feeds into the dose-response models to predict the probability of infection or illness. In order to convert pathogen concentrations into doses, reference was made to the treated wastewater pathogen concentrations and the ingestion rates for the water users (adults and children, in the case of swimming or other contact recreation,

Figure 8). Water ingestion rates applied in the QMRA were based on previous studies that have applied biochemical procedures to trace a decomposition product of chlorine-stabilizing chloroisocyanurate which passes through the surveyed swimmers' bodies unmetabolized (Dufour, Evans, Behymer, & Cantu, 2006; McBride, 2016).

Table 16 Pathogen concentrations applied in the QMRA model (based on monitoring conducted 18 times between 2015 and 2017)

Statistics	**Salmonella (#/L)**	**Campylobacter (#/100mL)**	***Giardia #/5L**	***Cryptosporidium #/5L**	***E.coli 0157: H7* (#/100mL)**
Min	2	2	1	1	0
5th per	2	2	1	1	0
Median	2	2	1.5	1	0
95th perc	2	11	8.1	4	0
Max	2	23	12	4	0
No of samples	18	18	18	18	18

* Subsequent infectivity assays on the oocysts where isolated were found to be non-infectious.

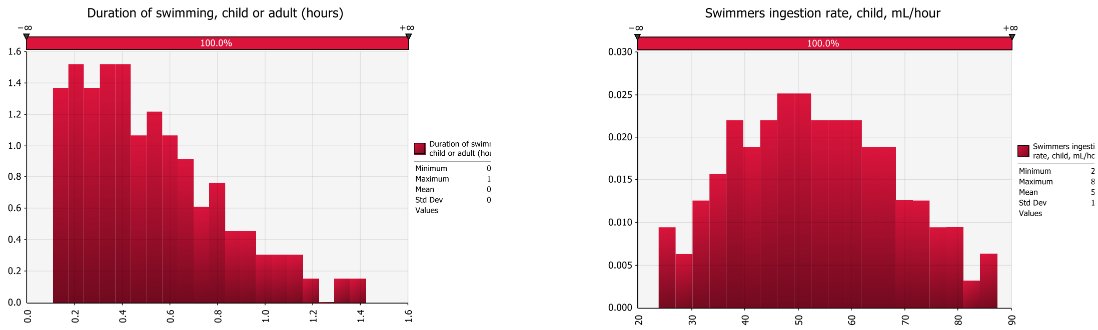

Figure 8 Duration of swimming and swimmers' ingestion rates applied in this QMRA.

Dose-response characterization

Dose-response models are mathematical functions that describe the dose-response relationship for specific pathogens, transmission routes and hosts. They estimate the risk of a response (for example, infection or illness) given a known dose of a pathogen. Dose-response relationships applied in this QMRA were taken from the peer-reviewed literature (UESPA 2010). Dose-response model equations and parameters used in this QMRA are presented in Table 16 and Appendix 1.

Table 17 Dose-response functions applied for specific pathogens in this QMRA

Reference Pathogen	Published dose-response model	Model parameters
Cryptosporidium spp.	Exponential (U.S. EPA, 2005a, 2006)	0.09
Giardia lamblia	Exponential (Haas et al., 1999; Rose et al., 1991)	0.0199
Campylobacter jejuni	Beta-Poisson (Medema et al., 1996; Teunis et al., 1996; 2005)	0.145 7.59
E. coli O157:H7	Beta-Poisson (Teunis et al., 2008b)	0.4 37.6
Salmonella enterica	Beta-Poisson (Haas et al., 1999)	0.3126 2884

Risk characterization

Information from the previous steps was incorporated into a Monte Carlo simulation to determine the likelihood of illness from exposure to zoonotic pathogens: *Campylobacter, E. coli O157:H7, Salmonella, Cryptosporidium* and *Giardia* (Appendix 10). The Monte Carlo simulation is a randomization method that applies multiple random sampling from distributions assigned to key input variables in a model, in a way that incorporates the uncertainty profiles of each key input variables into the uncertainty profile of the output. Typically, in a Monte Carlo model run, 100 individuals who do not have prior knowledge of existing contamination in the water are 'exposed' to potentially infectious water on a given day and this exposure is repeated 1,000 times. Therefore, the total number of exposures is 100,000. Monte Carlo simulations were undertaken using @Risk software (Palisade, NY).

The result of the analysis is a full range of possible risks associated with exposure to pathogens during the identified recreational activities. The predicted risk is reported as the IIR (individual illness risk), calculated as the total number of infection cases divided by the total number of exposures, expressed as a percentage. The IIR are then compared with thresholds defined in the New Zealand "*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*" (MfE/MoH 2003). The following **thresholds** apply:

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

5.4 QMRA Results and Discussion

The results of the QMRA analysis for individuals exposed to a range of reference pathogens under the various dilution scenarios are presented as individual illness risk (IIR) profiles in Appendices 2-11 and summarised in Table 18 and Table 19.

Regardless of the QMRA reference pathogen used, some conclusions were more or less the same; for instance, the risks associated with illness are generally higher with reducing levels of dilution of the AFFCO Plant discharge in the receiving water (Table 18 and Table 19). Risks were marginally higher during summer due to low flow and associated lower dilutions within the Kaituna River, compared to other times in the year. Although we recognize that sunlight-based ultraviolet inactivation may occur in the receiving environment to reduce the concentrations of pathogens in the receiving water in summer, in this QMRA we assumed a conservative stance that no microbial inactivation occurs in the Kaituna River following discharge[8] (Table 18).

5.4.1 Risk associated with swimming

The results of QMRA analysis generally show that **within the mixing zone (within** 350m downstream of the discharge) and outside of the mixing zone (i.e. 350m downstream of the discharge and beyond), a combination of wastewater treatment and the effect of dilution of the discharged wastewater occurring in the receiving environment is sufficient to reduce the individual illness risk (IIR) profiles to very low levels (below 0.2% in most cases). Risk profiles associated with swimming were below the "no observable adverse effects level" (1% threshold) for all the zoonotic pathogens tested. Even during slightly lower dilutions occurring in summer, the IIR was below the 1% threshold (Table 18). These results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge on the Kaituna River is **not more than minor** in terms of health risks associated with swimming.

5.4.2 Risk associated with consumption of raw shellfish

Outside the mixing zone

The results of QMRA analysis generally show that outside of the mixing zone (i.e. 350m downstream of the discharge and beyond), a combination of wastewater treatment and the effect of dilution of the discharged wastewater occurring in the receiving environment is sufficient to reduce the individual illness risk profiles to very low levels (below 0.2% in most cases). Risk profiles associated with swimming were below the "no observable adverse effects level" (1% threshold) for all the zoonotic pathogens tested. Even during slightly lower dilutions occurring in summer, the IIR was below the 1% threshold (Table 18). These results indicate that the effect of the AFFCO Rangiuru Plant meatworks discharge is **not more than minor** in terms of

[8] With the effect of microbial inactivation in the Kaituna River following discharge, risks reported here would be slightly lower than is reported in this study.

health risks associated with consumption of raw shellfish harvested at the Kaituna River.

Within the mixing zone

The results of QMRA analysis generally show that within the mixing zone (i.e. within 350m downstream of the discharge), enteric illness risks as a result of the discharge range from below NOAEL to high, depending on the level of dilution achieved, viz:

- If 50% dilution is achieved, low enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment only during summer months that are characterized by comparatively lower flows.
- If 25% or 10% dilution is achieved, regardless of the season, low enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment.
- If 5% dilution is achieved, low enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment. However, during summer months, illness risks increase from low to moderate.
- If 1% dilution is achieved, regardless of the season, high enteric illness risks are associated with consumption of raw shellfish harvested at the receiving environment.

The current study fills some crucial study gaps in the animal wastewater risk assessment terrain, as it shows using a robust microbiological monitoring program (FIB: 1995-date, pathogens: 2014-2017) and quantitative risk assessment, that the contribution the discharge makes to the health risk associated with contact recreation and consumption of raw shellfish harvested downstream in the Kaituna river is negligible, particularly outside of the mixing zone (i.e. 350m downstream of the discharge and beyond).

When evaluating these results, attention should be given to the absence of recreational activity (swimming) in the Kaituna River for a distance of 1,500 m downstream from the discharge point. As these QMRA results predict no observable adverse effects level beyond the 350m mark where 100% dilution is achieved, we predict that there will be no more than minor effects at the swimming site situated about 1500m downstream of the discharge. Also, in terms of the public health impact at the estuary, there will be no more than minor effects as a result of the discharge.

Table 18. Child Individual's Illness Risk (%) per 100 swimmers who are exposed to Kaituna River water that potentially contains zoonotic pathogens following AFFCO Rangiuru Plant wastewater discharge.

(a) Summer

Pathogen	Statistics	Outside the mixing zone (beyond 350m downstream of discharge)	Inside the mixing zone of discharge (within 350m downstream of discharge)				
		100% dilution	50% dilution	25% dilution	10% dilution	5% dilution	1% dilution
Campylobacter	IIR (%)	0.001	0.002	0.006	0.019	0.025	0.139
Cryptosporidium	IIR (%)	0.000	0.001	0.001	0.001	0.004	0.018
Giardia	IIR (%)	0.000	0.000	0.000	0.000	0.001	0.003
Salmonella	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.000
E.coli 0157:H7	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.000

(b) Annual

Pathogen	Statistics	Outside the mixing zone (beyond 350m downstream of discharge)	Inside the mixing zone of discharge (within 350m downstream of discharge)				
		100% dilution	50% dilution	25% dilution	10% dilution	5% dilution	1% dilution
Campylobacter	IIR (%)	0.001	0.002	0.005	0.014	0.023	0.117
Cryptosporidium	IIR (%)	0.000	0.000	0.000	0.001	0.003	0.014
Giardia	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.003
Salmonella	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.000
E.coli 0157:H7	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.000

IIR> 10%	High enteric illness risk
IIR (5.0-10%)	Moderate enteric illness risk
IIR (1.0-4.99%)	Low enteric illness risk
IIR <1%	NOAEL (i.e. no observable adverse effects level)

Table 19. Adult Individual's Illness Risk (%) per 100 individuals who consume raw shellfish harvested from the Kaituna River water potentially containing zoonotic pathogens due to the AFFCO Rangiuru Plant wastewater discharge.

(a) Summer

Pathogen	Statistics	Outside the mixing zone (beyond 350m downstream of discharge)	Inside the mixing zone of discharge (within 350m downstream of discharge)				
		100% dilution	50% dilution	25% dilution	10% dilution	5% dilution	1% dilution
Campylobacter	IIR (%)	0.554	1.027	1.813	3.526	5.448	11.645
Cryptosporidium	IIR (%)	0.036	0.076	0.151	0.368	0.722	3.105
Giardia	IIR (%)	0.007	0.013	0.028	0.072	0.146	0.666
Salmonella	IIR (%)	0.000	0.000	0.000	0.001	0.001	0.005
E.coli 0157:H7	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.000

(b) Annual

Pathogen	Statistics	Outside the mixing zone (beyond 350m downstream of discharge)	Inside the mixing zone of discharge (within 350m downstream of discharge)				
		100% dilution	50% dilution	25% dilution	10% dilution	5% dilution	1% dilution
Campylobacter	IIR (%)	0.534	0.833	1.491	2.970	4.685	10.528
Cryptosporidium	IIR (%)	0.028	0.060	0.118	0.305	0.588	2.501
Giardia	IIR (%)	0.012	0.010	0.024	0.058	0.113	0.527
Salmonella	IIR (%)	0.000	0.000	0.000	0.001	0.001	0.004
E.coli 0157:H7	IIR (%)	0.000	0.000	0.000	0.000	0.000	0.000

IIR> 10%	High enteric illness risk
IIR (5.0-10%)	Moderate enteric illness risk
IIR (1.0-4.99%)	Low enteric illness risk
IIR <1%	NOAEL (i.e. no observable adverse effects level)

6. Conclusion

A combination of water quality monitoring downstream of the discharge, mass balance modelling and quantitative microbial risk assessment provide overwhelming evidence that:

- the AFFCO plant discharge does not affect the recreational water quality of the receiving water at the edge of the mixing zone (i.e. 350m downstream of the discharge and beyond).
- health risks in terms of enteric illnesses to individuals who use sites 350 m downstream of the discharge (and beyond) for recreational purposes are below the "no observable adverse effects level".
- health risks in terms of enteric illnesses to individuals who consume raw shellfish harvested at sites 350 m downstream of the discharge (and beyond) are below the "no observable adverse effects level".

The effect of the AFFCO Plant wastewater 350 m downstream of the discharge (and beyond) is <u>therefore not more than minor</u>.

Within the mixing zone (i.e. less than 350m downstream of the discharge), however, enteric health risks as a result of the discharge range from low to high, depending on the level of dilution achieved.

7. Recommendation

We recommend that as part of consent conditions,

i. an upstream site be designated and included in the receiving water faecal indicator bacteria compliance monitoring program.
ii. continuous monitoring of receiving water *Campylobacter* concentrations in site (i) above and at the downstream compliance site, given that the pathogen was most frequently detected in the treated wastewater.

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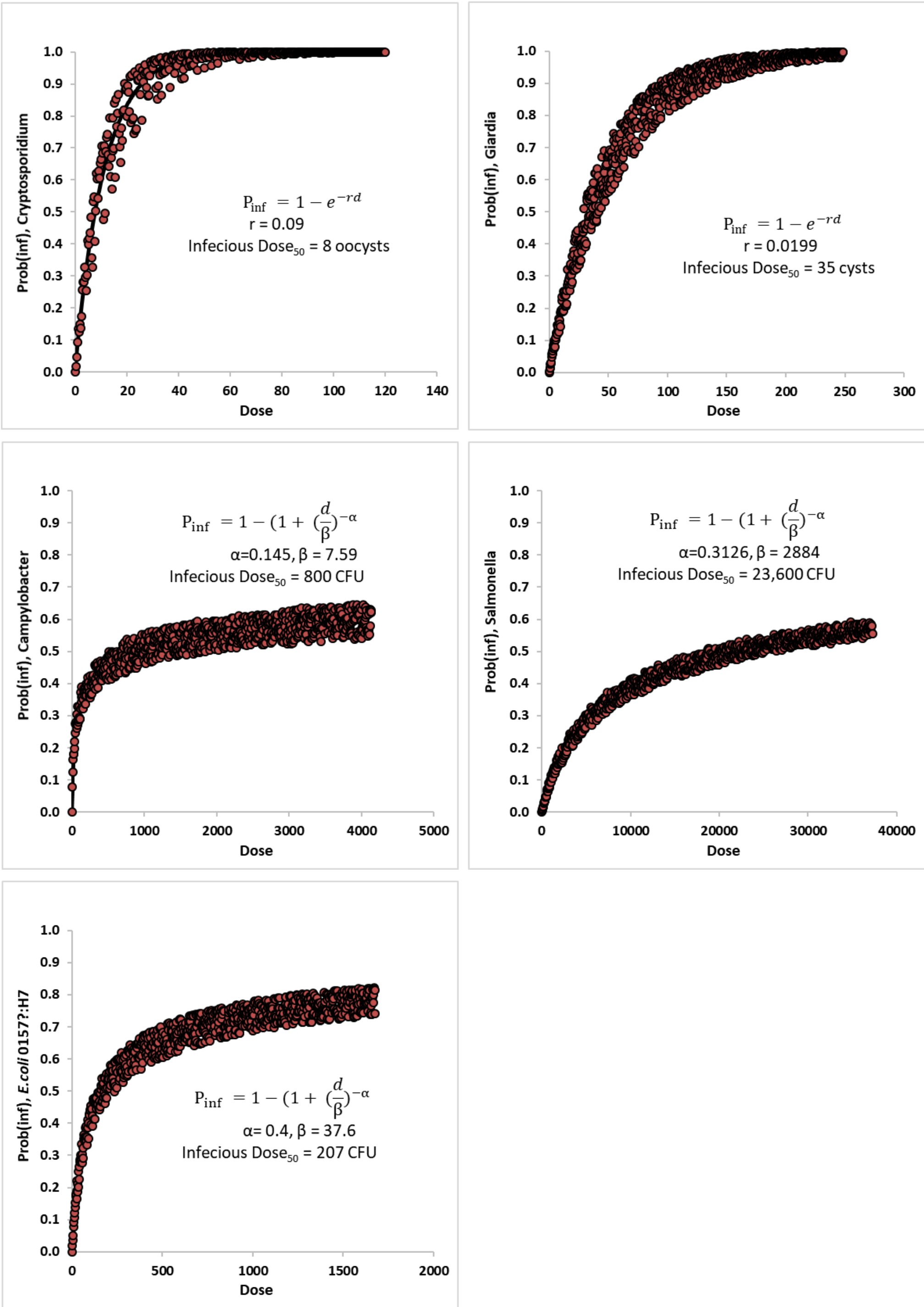
Appendix 1 Plots of individual dose response curve fitted for meatworks-related pathogens in this QMRA.



Included in each plot is the dose-response model applied, the model parameters and the infectious dose$_{50}$ i.e. the amount of pathogen (measured in specified units of microorganisms) required to cause an infection in the 50% of exposed host population.

Appendix 2. Individual's Illness Risk (%) and predicted number of illness cases per 100 swimmers who are exposed to Kaituna River water that potentially contains *Campylobacter* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	1	0	0	0	0	0
95 th perc.	1	0	0	0	0	0
97.5 th perc.	1	0	0	0	0	0
99 th perc.	2	1	1	0	0	0
Maximum	3	2	2	1	1	1
Mean (%)	0.14	0.02	0.02	0.01	0.00	0.00

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	1	0	0	0	0	0
95 th perc.	1	0	0	0	0	0
97.5 th perc.	1	0	0	0	0	0
99 th perc.	1	1	1	0	0	0
Maximum	4	2	1	1	1	1
Mean (%)	0.12	0.02	0.01	0.01	0.00	0.00

Appendix 3. Individual's Illness Risk (%) and predicted number of illness cases per 100 swimmers who are exposed to Kaituna River water that potentially contains *Cryptosporidium* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	1	0	0	0	0	0
Maximum	2	1	1	1	1	1
Mean (%)	0.02	0.00	0.00	0.00	0.00	0.00

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	1	0	0	0	0	0
Maximum	2	1	1	1	1	1
Mean (%)	0.01	0.00	0.00	0.00	0.00	0.00

Appendix 4. Individual's Illness Risk (%) and predicted number of illness cases per 100 swimmers who are exposed to Kaituna River water that potentially contains *Giardia* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	1	1	1	1	1	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	2	1	1	1	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 5. Individual's Illness Risk (%) and predicted number of illness cases per 100 swimmers who are exposed to Kaituna River water that potentially contains *Salmonella* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	0	0	0	0	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	0	0	0	0	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 6. Individual's Illness Risk (%) and predicted number of illness cases per 100 swimmers who are exposed to Kaituna River water that potentially contains *E.coli* 015: H7 following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	0	0	0	0	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	0	0	0	0	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 7. Individual's Illness Risk (%) and predicted number of illness cases per 100 individuals who consume raw shellfish harvested from Kaituna River water potentially containing *Campylobacter* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	12	5	3	1	1	0
75 th perc.	15	8	5	3	2	1
80 th perc.	16	8	6	3	2	1
90 th perc.	18	10	7	4	3	2
95 th perc.	20	11	8	5	3	2
97.5 th perc.	21	13	9	6	4	3
99 th perc.	23	14	11	7	5	3
Maximum	31	23	19	15	9	9
Mean (%)	11.64	5.45	3.53	1.81	1.03	0.55

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	10	4	3	1	1	1
75 th perc.	14	7	4	2	1	1
80 th perc.	15	7	5	3	2	2
90 th perc.	17	9	6	4	2	2
95 th perc.	19	10	7	4	3	3
97.5 th perc.	20	12	9	5	4	4
99 th perc.	22	13	10	6	4	4
Maximum	32	27	18	13	12	10
Mean (%)	10.53	4.69	2.97	1.49	0.83	0.83

Appendix 8. Individual's Illness Risk (%) and predicted number of illness cases per 100 individuals who consume raw shellfish harvested from Kaituna River water potentially containing *Cryptosporidium* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	2	0	0	0	0	0
75 th perc.	5	1	1	0	0	0
80 th perc.	5	1	1	0	0	0
90 th perc.	7	2	1	1	0	0
95 th perc.	9	3	2	1	1	0
97.5 th perc.	10	4	2	1	1	1
99 th perc.	12	4	3	2	1	1
Maximum	21	8	6	4	3	2
Mean (%)	3.11	0.72	0.37	0.15	0.08	0.04

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	2	0	0	0	0	0
75 th perc.	4	1	0	0	0	0
80 th perc.	4	1	1	0	0	0
90 th perc.	6	2	1	1	0	0
95 th perc.	8	2	2	1	1	1
97.5 th perc.	9	3	2	1	1	1
99 th perc.	11	4	3	2	1	1
Maximum	17	7	5	3	2	2
Mean (%)	2.50	0.59	0.30	0.12	0.06	0.04

Appendix 9. Individual's Illness Risk (%) and predicted number of illness cases per 100 individuals who consume raw shellfish harvested from Kaituna River water potentially containing *Giardia* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	1	0	0	0	0	0
80 th perc.	1	0	0	0	0	0
90 th perc.	2	1	0	0	0	0
95 th perc.	3	1	1	0	0	0
97.5 th perc.	3	1	1	1	0	0
99 th perc.	4	2	1	1	1	0
Maximum	8	4	3	2	2	1
Mean (%)	0.67	0.15	0.07	0.03	0.01	0.01

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	1	0	0	0	0	0
80 th perc.	1	0	0	0	0	0
90 th perc.	2	1	0	0	0	0
95 th perc.	2	1	1	0	0	0
97.5 th perc.	3	1	1	0	0	0
99 th perc.	4	1	1	1	0	1
Maximum	8	4	3	2	2	1
Mean (%)	0.53	0.11	0.06	0.02	0.01	0.01

Appendix 10. Individual's Illness Risk (%) and predicted number of illness cases per 100 individuals who consume raw shellfish harvested from Kaituna River water potentially containing *Salmonella* following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	Inside the mixing zone of discharge (within 350m downstream of discharge)					Outside the mixing zone (beyond 350m downstream of discharge)
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	2	1	1	1	0	1
Mean (%)	0.01	0.00	0.00	0.00	0.00	0.00

(b) Annual

Location in Kaituna River	Inside the mixing zone of discharge (within 350m downstream of discharge)					Outside the mixing zone (beyond 350m downstream of discharge)
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	1	1	1	1	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 11. Individual's Illness Risk (%) and predicted number of illness cases per 100 individuals who consume raw shellfish harvested from Kaituna River water potentially containing *E.coli* 015: H7 following AFFCO Rangiuru Plant wastewater discharge

(a) Summer

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	0	0	0	0	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00

(b) Annual

Location in Kaituna River	**Inside the mixing zone of discharge (within 350m downstream of discharge)**					**Outside the mixing zone (beyond 350m downstream of discharge)**
Statistics	1% dilution	5% dilution	10% dilution	25% dilution	50% dilution	100% dilution
50 th perc.	0	0	0	0	0	0
75 th perc.	0	0	0	0	0	0
80 th perc.	0	0	0	0	0	0
90 th perc.	0	0	0	0	0	0
95 th perc.	0	0	0	0	0	0
97.5 th perc.	0	0	0	0	0	0
99 th perc.	0	0	0	0	0	0
Maximum	0	0	0	0	0	0
Mean (%)	0.00	0.00	0.00	0.00	0.00	0.00