New Plymouth WWTP: Wastewater characterisation and assessment of microbiological effects

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Prepared by:
Rebecca Stott
David Wood
Reza Moghaddam

For any information regarding this report please contact:

Rebecca Stott
Environmental Health Microbiology
Aquatic Pollution
+64 7 859 1892
rebecca.stott@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

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The New Plymouth Wastewater Treatment Plant (NPWWTP), also known as the Waiwhakaiho Wastewater Treatment Plant, is operated by New Plymouth District Council (NPDC). NPDC has a resource consent to discharge treated wastewater derived from a mix of industrial and domestic sewage via an outfall pipe and diffuser array to the Tasman Sea north of the mouth of the Waiwhakaiho River. As part of the current consent conditions, a reassessment of the potential human health risks arising from the discharge of treated wastewater is required.

This report provides a context that may be used to support the recent technical work in the 2023 Quantitative Microbial Risk Assessment (QMRA) that assessed the potential risks from the discharge of treated wastewater from the NPWWTP and the impact of bypass events. As part of this risk assessment, NIWA was engaged to assess data associated with the wastewater treatment plant and related receiving environment to assess treatment performance and environmental impact. Wastewater, recreational water quality and shellfish-related quality data were reviewed to identify and characterise known potential sources of faecal contaminants or events likely to cause adverse impacts in the coastal environment.

Where possible, the health risk arising from faecal contaminating sources or events has been identified and assessed. Nevertheless, it is important to acknowledge that limitations in microbiological detection methods such as censored values (those below detection or quantification limits), inability to assess norovirus viability, unequal datasets or limited data availability introduce uncertainties in risk analyses. Consequently, in our assessment of the data, we have adopted a conservative approach as detailed in the report.

New Plymouth Wastewater Treatment Plant discharge

Wastewater monitoring indicates a consistent microbiological quality of disinfected treated effluent with low faecal indicator bacteria (FIB) levels typically below 10 counts/100mL and low levels of norovirus generally below 1000 genome copies/L (gc/L).

Norovirus was consistently detected in influent wastewaters year-round, exhibiting extreme variability in concentrations ranging from 10^2 to 10^5 gc/L for GI and 10^4 to 10^6 gc/L for GII. Treatment at the NPWWTP reduced the median concentrations to <13 GI gc/L and < 50 GII gc/L in tertiary-treated disinfected effluent discharged to the environment.

Under normal flow operating conditions, removal of norovirus by the NPWWTP appears relatively consistent, with a conservative estimate of median $\log_{10}$ reduction of 2.5 $\log_{10}$ GI and 3.4 $\log_{10}$ GII (based on non-censored concentration values). While norovirus can be effectively removed during wastewater treatment, treated effluent may still contain norovirus on occasions (up to 10^2 GI gc/L and 10^3 GII gc/L) discharged into the coastal environment. The potential impact on recreational risk is unclear from the data as seasonal information on norovirus in final effluent is currently limited to a single measurement for the summer months (December to February) when recreational exposure is likely greatest.

Although there was no evidence of deterioration in treatment performance over time, there was slight seasonal variation in wastewater treatment efficiency throughout the year with median FIB flux or instantaneous load increasing in summer and again in late autumn – early winter.

Recreational water quality

Recreational water quality data indicate spatial variations in health risks along the New Plymouth coastline with the greatest potential risk observed at sites near the outfall (within 500m SW and 300m NE) and in close proximity to the mouth of the Waiwhakaiho River. Despite this, available data does not indicate a deleterious impact of wastewater discharge on Faecal Indicator Bacteria content in receiving waters during the summer bathing season.

FIB concentrations in WWTP effluent are markedly lower than in marine waters at coastal sites both up and downcoast from the outfall and also in comparison to the Waiwhakaiho River discharging into the coastal zone SW of the outfall. Enterococci concentrations in the treated effluent, (based on a limited dataset), range from <1-10 /100 mL, notably lower than enterococci concentrations in the Waiwhakaiho River (95th percentile 4460 enterococci/100 mL). Coastal sites near the outfall also exhibit higher enterococci concentrations than treated effluent with 95th percentile concentrations of 960 counts/100 mL at 500 m SW of outfall (Waiwhakaiho) and 350 counts/100 mL at 300 m NE of outfall. Similar observations and spatial trends are seen for faecal coliform concentrations in treated effluent in comparison to coastal sites and freshwater sources.

The water quality data strongly indicate that the Waiwhakaiho River is probably a significant source of faecal bacterial contamination in the local receiving environment, potentially affecting bathing water quality at sites along the coastline. The highest concentrations of FIB at the Waiwhakaiho Reef site are likely attributable to the input of FIB from freshwater inflows from the river along with other potential sources such as avian inputs from seagulls congregating on intertidal reefs.

Impaired shoreline water quality with regards to faecal indicator bacteria, is more likely associated with contaminants from diffuse sources and freshwater inputs rather than from the wastewater discharge of the NPWWTP.

Most of the coastal recreational water quality sites are either “B” or “C” graded (based on 95th percentile concentrations of enterococci), indicating a gastrointestinal illness (GI) risk of greater than 1% - a level of risk higher than estimated in the 2023 QMRA for normal flow operation but relate to all risks.

For two sites nearest to the outfall:

- a >10% risk of GI illness and >3.9% AFRI illness exists for the Waiwhakaiho Reef site (~W2), and
- a 5-10% GI illness and 1.9-3.9% AFRI illness risk exists for the site 300m NE of the outfall (E1).

For sites further along the coast:

- to the SW along the coastline, typically a ≤5% GI illness risk and ≤1.9% AFRI illness risk exists, and
- for sites further NE along the coastline a > 5% GI illness and >1.9% AFRI illness risk exists.

The recreational risks associated with sites SW and NE of the outfall reflect the impact of faecal contaminants from all sources and are larger than the average risks indicated by the 2023 QMRA.

This outcome is consistent with QMRA estimates, which provide the **incremental risk associated exclusively with the NPWWP discharge**, i.e., it does not account for other contaminant sources.

Shellfish quality

Coastal sites generally exhibited microbial quality within the guidelines for recreational shellfish harvesting, with median Faecal coliform (FC) concentrations below the recommended threshold of 14 FC/100 mL. However, most sites had more than 10% of samples exceeding a threshold of 43 FC/100 mL, indicating that the overall suitability for recreational shellfish harvesting, as advised by MfE/MoH (2003), was limited to a few sites. Bell Block marginally exceeded the specified sample requirement.

However, monitoring of green-lipped mussels at several sites indicates norovirus contamination and an adverse impact of wastewater discharge on shellfish associated health risk. Shellfish monitoring provided evidence that:

- at a potential impact site near to the outfall, mussels are frequently contaminated, but,
- contamination of mussels is less prevalent at a site further up the coastline and distant from the outfall,
- norovirus are often detected below limits of quantitation in contaminated mussels under normal flow operations, and
- for bypass flow events, greater contamination levels increase the exposure risk for shellfish consumption and are more widespread and distributed further along the coastline.

The observed prevalence and levels of norovirus contamination from the mussel monitoring align with the risk estimates in the QMRA highlighting spatial variation in health risks. The higher prevalence of contamination in shellfish closest to the NPWWTP outfall where concentration of norovirus is likely highest aligns with the expected dilution effect increasing with distance from the outfall.

Levels of quantified contamination in mussels collected during normal flow operation extended up to 600 genome copies/g (gc/g) at Waiwhakaiho Reef and 400 gc/g on a separate occasion at Bell Block. However, when detected, levels of norovirus were often below 80 gc/g. During bypass flow, when the level of treatment is reduced, higher levels of contamination were found at both Bell Block (110 GII gc/g) and extremely high at Waiwhakaiho (17,000 GII gc/g).

Guidelines do not exist for virus levels in shellfish, though guideline values exist for *E. coli* levels in shellfish flesh gathered for commercial purposes. The European Union has proposed a norovirus standard for commercial shellfish of 200 gc/g, which is the sum of the two norovirus genogroups (GI and GII). In practice, this would mean that the measured values of GI and GII would be required to be below the level of quantification (e.g., 80 gc/g in the NPWWTP study) to meet the standard. Thus, health risks associated with recreational shellfish gathering at reefs near the NPWWTP outfall and raw shellfish consumption might be considered low but could still represent a health risk, and consumption is not advisable.

1 Introduction

The New Plymouth Wastewater Treatment Plant (NPWWTP), also known as the Waiwhakaiho Wastewater Treatment Plant, is operated by New Plymouth District Council (NPDC). NPDC has a resource consent to discharge treated wastewater derived from a mix of industrial and domestic sewage via an outfall pipe and diffuser array to the Tasman Sea north of the mouth of the Waiwhakaiho River. As part of the current consent conditions, a reassessment of the potential human health risks arising from the discharge of treated wastewater is required that specifically addresses bypass discharges of partially treated wastewater.

To address consent requirements, New Plymouth District Council commissioned NIWA to prepare a Quantitative Microbial Risk Assessment (QMRA) of human health risks estimated to arise from recreation in, or consumption of shellfish gathered from, waters affected by the discharge of treated wastewater from the Waiwhakaiho WWTP. The QMRA was also to compare the risks derived from an earlier 2012 QMRA authored by McBride (2012). The results from the 2023 QMRA, reported in Wood and Stott (2023), relate to the incremental risks associated with the NPWWTP discharge.

As a component of the QMRA work, NIWA was also contracted to undertake a microbiological assessment of the receiving water for the marine discharge environment to assist with the assessment of health risks. This assessment focuses primarily on faecal indicator bacteria (FIB) and provides a broader context for health risks to recreational users, as it incorporates other contaminant sources (e.g., diffuse, urban runoff, wildlife) in addition to NPWWTP. This "microbiological context" forms the basis of this report.

Data used to establish the microbiological context for the marine discharge environment included:

- compliance monitoring of wastewater discharge volumes, rates and concentrations of faecal indicator bacteria such as faecal coliforms[1] and enterococci measured in the discharge and receiving environment,
- wastewater concentrations of norovirus from monitoring activities,
- microbiological data for receiving environments (shoreline FIB concentrations), derived from available consent monitoring and from coastal recreational water quality monitoring (undertaken by Taranaki Regional Council as part of recreational bathing beach surveys and compliance monitoring), and,
- shellfish monitoring for norovirus (undertaken by Taranaki Regional Council (TRC) during 2013-2022).

These data were used to estimate the risks to recreational users (particularly during the bathing season), using criteria and guideline values from the New Zealand Recreational Water Quality Guidelines (Ministry for the Environment and Ministry of Health, 2003). It is important to note that these Guidelines should not be used to assess risks from wastewater discharges, as the treatment process may alter the relationship between FIB and pathogens. This lack of a reliable relationship is one of the key reasons why the QMRA approach was chosen to estimate risk. However, analysing FIB data and comparing them with the Guidelines does provide another way to estimate the prevailing health risk to recreational water users from contamination sources other than well treated

[1] Faecal coliforms are now typically considered as thermotolerant coliforms

wastewater, particularly during recreational or bathing seasons. Data were also used to assess spatial patterns of risk.

The WWTP at New Plymouth consists of initial screening followed by activated sludge aeration for biological secondary treatment and disinfection of clarified effluent using sodium hypochlorite for tertiary treatment. On occasion, “bypass” events occur. In these cases, flow in the Bypass channel is dosed with chlorine at the beginning of the channel and then again after this flow has mixed with the treated effluent. The disinfected treated effluent is discharged to the Tasman Sea via an ocean outfall which is approximately 450 m offshore and located 1 km north of the WWTP. Appendix A provides a schematic of the WWTP and treatment units.

A monitoring plan is in place for the WWTP in accordance with the resource consent to discharge the treated wastewater (NPDC 2022). As part of the monitoring plan, concentrations of faecal indicator bacteria (FIB) are measured three times per week from grab samples of the disinfected discharged effluent to assist in confirming disinfection is being achieved. Composite 24 hr samples are also collected twice a year for analysis of norovirus (genogroup GI and GII) and confirmation of disinfection. Sampling for norovirus at the WWTP is liaised with TRC for monitoring of norovirus in mussels.

Although FIB concentrations may provide some indication of the effect that discharge of treated wastewater has on the receiving waters, this report does not attribute risk to any specific source. This is particularly relevant for discharged wastewaters as the relationship between indicator and pathogen is not assured, because whilst wastewater treatment may effectively reduce FIB concentrations, other pathogens may be less affected by treatment processed and thus still present in concentrations that represent a potential health risk to exposed members of the public.

2 Methods

Water quality and discharge data were provided by New Plymouth District Council. NIWA collated available compliance, state of environment and other relevant monitoring data for wastewater discharge, receiving environment, shoreline and shellfish flesh monitoring. Data were reviewed and the outcomes of an exploratory data analysis exercise were summarised, including:

- preparation of summary statistics,
- graphical summary of results, and,
- an overview of treatment performance and efficiency.

This information was intended to provide a context for the 2023 QMRA.

2.1 Data sources

2.1.1 Wastewater

Wastewater quality and discharge data were provided by NPDC and supplied to NIWA in a variety of formats[2]. Datasets used for this assessment were derived from several different monitoring programmes. Consequently, not all data sets are of equivalent length and monitoring of selected variables was initiated or discontinued during the life of some programmes. In most cases, data were available for the period 2012-2022; where additional data were available, it was included.

For WWTP flows, influent flows (L/s) were supplied for both Bioreactor flows from which total influent flow and loads (m^3/d) were estimated for 2012-2022. Treated effluent flow (L/s) was supplied as daily averages for 5 years' worth of data from 2018 to 2022[3].

Faecal indicator bacteria (FIB) concentrations were supplied as monthly data for FIB in effluent for 2017-2022 (Table 2-1). Frequency of analysis for faecal coliforms was typically three times per week. Infrequent analysis of enterococci was also undertaken (typically 1-5 times per year) to enable comparison with results of bacteriological monitoring of receiving waters by TRC[4]. Data were used with limited modification including:

- calculation of instantaneous load as a product of the daily average wastewater flow (discharge rate) and FIB concentration on the day the grab sample was collected, and
- replacement of results reported as less than a detection limit with a value half of the detection value for flux estimates; results were not modified for deriving percentile concentrations.

[2] MS Excel workbooks produced by NPDC or TRC; Bioreactor Flows and temperature.xlsx; NPWWTP 12 years daily flow & Temp.xlsx; Copy of SCAD-20231110-113147 Effluent Flow NP WWTP 2012-2022.xlsx; NPWWTP Effluent Biological Monthly Report – ending 2018-01.xlsx, Report – ending 2019-01.xlsx, Report – ending 2020-01.xlsx,Report-ending 2021-01.xlsx, Report-ending 2022-01.xlsx; norovirus only data 2010_2020.xlsx; FROD-#3235042-v1-NPWWTP_shoreline_bacto_data_2014-2021_(biennial)_xls; Word documents supplied by TRC FRODO-#2839321-v1-MAR2008_Bathing_beach_water_quality_survey_-_NPWWTP_outfall_Summer_2021.docx,; PDF documents FROD-#3223556-v1-NPWWTP_Norovirus_reports_December_2020.pdf

[3] Effluent flow data is only available from 23/8/2018 onwards after equipment was upgraded (Amy Quattlebaum, Quality and Compliance Lead, NPDC, pers, comm.). Data before that had been auto-populated with an average of 274.2938 L/s and was therefore discarded.

[4] Receiving waters monitoring for FIB was replaced in 2022 with effluent monitoring for FIB following recommendations in the TRC 2021/2022 Annual Compliance Monitoring Report.

Table 2-1: Faecal indicator bacteria and pathogen monitoring for NP WWTP undertaken by NPDC[5].

Micro-organism	WWTP sampling site	Frequency of sampling	Sample type
Faecal coliform	Influent	monthly	24 hr composite (flow proportional)
	Effluent	3 times per week	Grab[6]
Enterococci	Effluent	1-4 times per year	Grab
Norovirus (GI and GII)	Influent	1-2 times per year	24 hr composite
	Clarifier effluent (before chlorination)	1-2 times per year	Grab composite from 3 clarifiers
	Effluent	1-2 times per year	24 hr composite

Norovirus monitoring of influent and effluent from the NPWWTP was added to the monitoring programme in accordance with condition 14 (e) of consent 0882-4. Norovirus data was supplied for influent, composited clarifier samples (before disinfection) and treated effluent (post disinfection) from 2013 to 2021 (post upgrade of the NPWWTP). From 2013 to 2017, the frequency of monitoring was restricted to one sampling event per year. From 2017 onward, sampling frequency was increased to twice per year (as recommended in the NPWWTP monitoring plan).

The dataset for norovirus genome concentrations in wastewaters (influent and effluent at NPWWTP) and in shellfish is limited, comprising fewer than 20 data points. In addition, the methodology error for norovirus detection remains unknown. Observed levels of norovirus in the effluent are also generally low, resulting in observations which are censored or, in other words, below the limit of quantification (<50 gc/L) and/or below the level of detection (<13 gc/L). These factors introduce significant uncertainty in risk assessment.

Whilst censored data was factored into the norovirus analysis (using the value of the censored data as a conservative measure), the precision of the inferences drawn under these circumstances remains uncertain. Therefore, it is important to acknowledge these limitations when evaluating the conclusions derived from the data.

2.1.2 Receiving environment

Locations (longitude and latitude) of sites east and west of the outfall (12 East, 18 West) were supplied by NPDC for inclusion in the QMRA analysis as reported in Wood and Stott (2023).

Receiving environment data was supplied for concentrations of several faecal indicator bacteria (faecal coliforms, *E. coli*, enterococci) for Recreational Water Quality sites monitored by Taranaki Regional Council up- and downcoast of the wastewater outfall. Sites were sampled during dry weather conditions[7]. In addition, data from shoreline bacteriological surveys from three coastal sites

[5] TRC also undertake analysis of faecal coliforms and enterococci twice yearly of influent grab samples and weekly of effluent during summer bathing season for faecal coliforms, *E. coli* and enterococci as part of the TRC inspection component of the NPWWTP monitoring programme (NPDC 2022).

[6] The sample is dechlorinated at the time of sampling by adding sodium thiosulphate to the sample.

[7] The Recreational Water Quality Monitoring Programme has recently been revised and shifted from a dry weather/trend monitoring approach to that of a fixed day/all-weather approach. The intention is to enable collection of data more representative of the full range of weather conditions in order to better inform the public health risk. Sampling during wet weather will likely result in higher FIB concentrations due to inputs from land runoff into waterways and downstream into coastal areas. In response to these changes in environmental monitoring, FIB monitoring of NPWWTP effluent will be undertaken on a weekly basis during summer season (Dec – Feb) and will replace the shoreline monitoring at the three coastal sites in proximity to the outfall.

in the vicinity of the marine outfall and at a site located on the Waiwhakaiho River downstream of Lake Rotomanu was also utilised. Data was provided from 2017 to 2022 by TRC for *E. coli*, faecal coliforms and enterococci and covered six bathing seasons (2013-2014, 2014-2015, 2016-2017, 2019-2020, 2021-2022, 2022-2023). Not all sites were monitored for the same duration.

From November 2021, the methodology for enterococci at five sites (Bell Block, Fitzroy, East End, Ngamotu and Back Beach), changed from CFU (colony forming units) to MPN (most probable number) which increased the reported detection limit for enterococci from that previously. For simplicity, the results from both methods have been treated as comparable.

Information from the Recreational Water Quality monitoring sites and shoreline monitoring sites were cross-referenced with the QMRA site locations where possible. Hence some environmental monitoring sites are roughly analogous to the QMRA sites.

2.1.3 Shellfish

As a requirement of condition 14 (consent 0882-4), shellfish monitoring for microbial contamination was integrated into the consent compliance monitoring plan for the NPWWTP. Since 2012, flesh from green lipped mussels is monitored for norovirus (GI and GII genotypes) at two potential impacted sites; Bell Block (Mangati Reef) located north of the outfall and Waiwhakaiho Reef located 500 m southwest of the outfall.

Shellfish sampling results for norovirus (GI and GII) were supplied for 2010-2022 for green lipped mussel[8] results from TRC. Frequency of shellfish sampling is twice yearly for normal WWTP operation and during a Bypass flow event, should that occur. Analysis for norovirus (RT-qPCR) is performed on shellfish flesh composited from around 20 mussels collected from each site. Norovirus testing using the ESR method includes dissection of shellfish digestive gland tissue[9] followed by a proteinase K digestion step, extraction of viral RNA from the tissue digest and analysis of the RNA in separate norovirus-specific GI and GII real-time RT-PCR assays. Most of the analyses for shellfish testing were below the limit of quantitation (80 gc/g tissue) but above the limit of detection.

[8] No significant populations of filter feeding bivalves other than green lipped mussels are reported to be recreationally harvested in the area (NPDC 2022).

[9] The method is based on ISO 15216-2:2019(E). Microbiology of the food chain-Horizontal method for determination of hepatitis A virus and norovirus using real-time RT-PCR, Part 2: Method for detection.

3 Results

Data were examined to characterise the discharged wastewater and the nature and scale of its effects on the environment. Exploratory analysis was undertaken using TimeTrends V11 and R 4.2.2.

The locations of various sample points are indicated in Figure 3-16 for QMRA sites, coastal recreational water monitoring, shoreline monitoring and shellfish sampling for norovirus (TRC).

3.1 New Plymouth WWTP discharge

Time series data for wastewater outflow (m^3/d) is summarised in Figure 3-1 for daily average rates and in Figure 3-2 for monthly characteristics. Data indicates discharge rates fluctuate throughout the year and are punctuated intermittently by short periods of considerably higher flows.

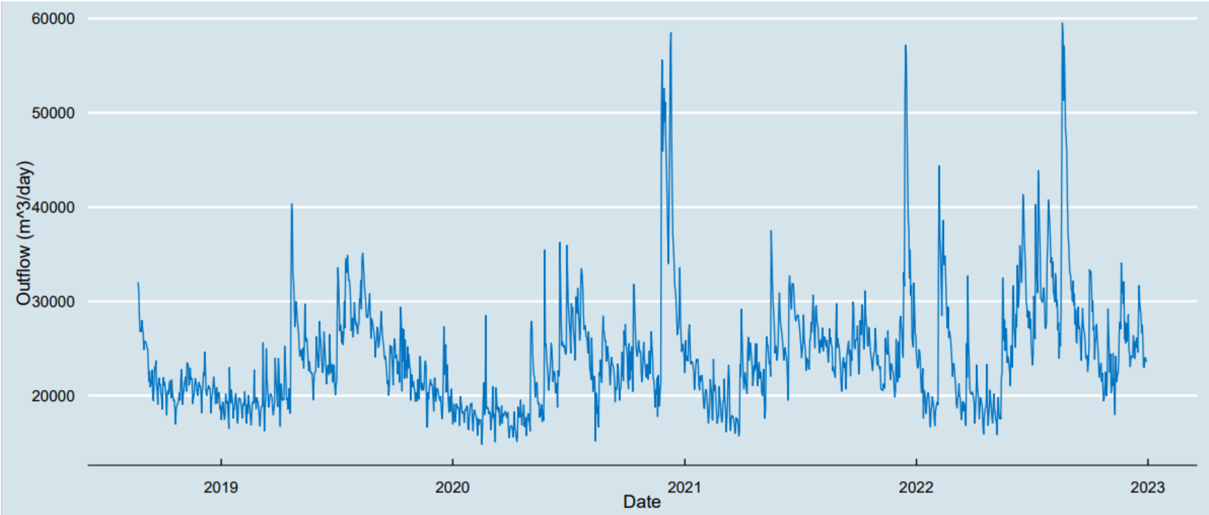

Figure 3-1: **Daily average timeseries for wastewater discharge from NPWWTP.** Data supplied by NPDC.

There is evidence of seasonal variation in wastewater outflow volumes with notably larger median and mean discharge rates in the winter months, June to August, and also during December (Figure 3-2). Conversely, late summer and early spring months experience lower flows influenced by generally drier conditions in the sewer catchment.

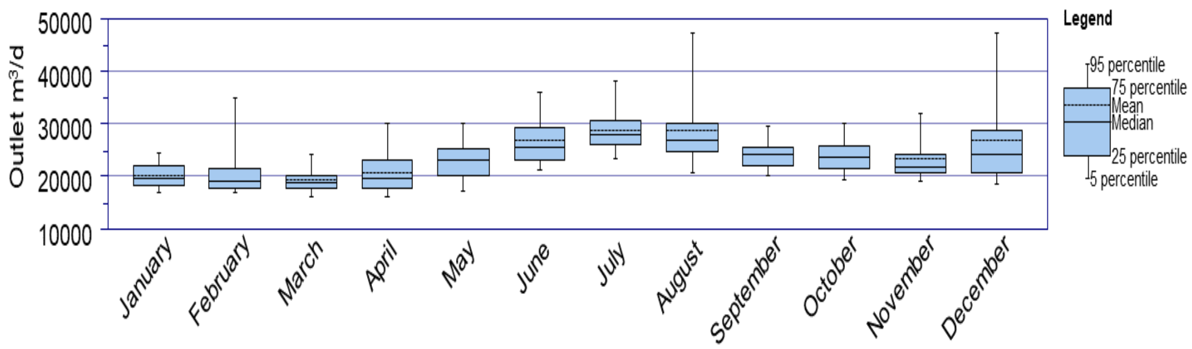

Figure 3-2: Seasonal (monthly) summary of daily wastewater outflow characteristics (2018-2022 inclusive). Note: y-axis begins at 10,000 m^3/d.

Annual mean outflow rates range from 21,499 m^3/d (2018) to 26,250 m^3/d (2022), indicating a consistent upward trend in daily average flow on an annual basis (Figure 3-3). Deseasonalised trend analysis suggests that this increase is approximately 5% per year (Appendix A).

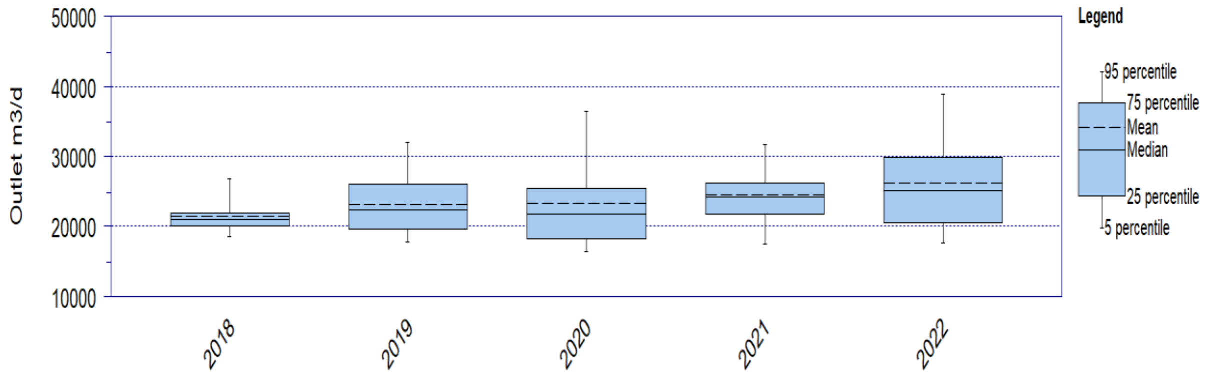

Figure 3-3: Annual discharge characteristics, 2018-2022 calendar years. Summary of daily average load (m^3/d) on an annual basis. Note: y-axis begins at 10,000 m^3/d.

3.2 Wastewater microbiological characteristics

3.2.1 Faecal indicator bacteria

Faecal indicator bacteria (faecal coliforms and enterococci) are monitored in the final treated effluent to confirm disinfection is achieved. A time series of these two FIBs is provided in Figure 3-4 along with levels of total chlorine (g/m^3).

The consent limit for Total Available Chlorine (TAC) should be no less than 0.3 g/m^3 in effluent prior to entering the outfall pipe (special condition 10). Data in Figure 3-4 shows that chlorine levels in the disinfected clarified effluent is typically greater than 0.5 g/m^3. Levels of faecal coliform concentrations in the treated wastewater varies over two orders of magnitude. However, faecal coliform concentrations in the outflow are generally below 10 FC/100 mL, with low levels consistent with measured TAC concentrations signifying effective disinfection. On occasions, elevated concentrations of faecal coliforms are observed, but these do not appear to coincide with relatively low TAC levels nor high flows.

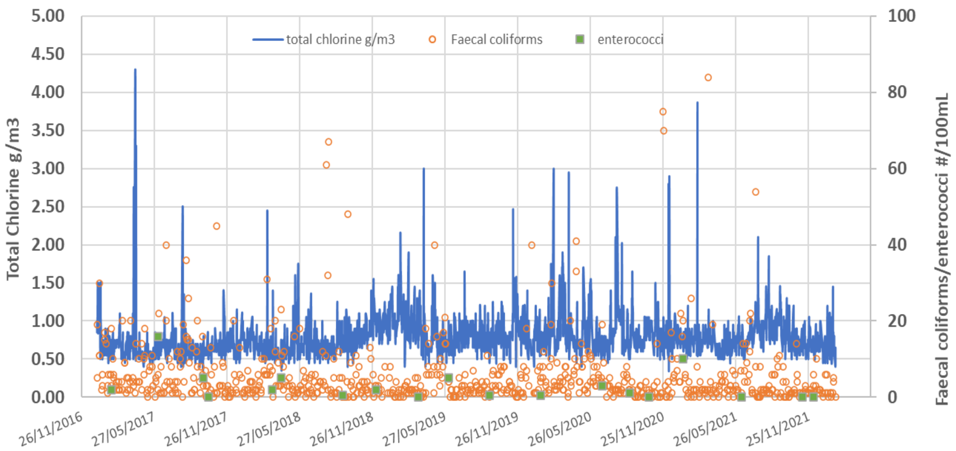

Figure 3-4: Time series of faecal coliform concentration and Total Chlorine in treated effluent from NPWWTP. Jan 2017 to Jan 2022 inclusive. Uncensored values shown.

Monthly median faecal coliform concentrations in the treated wastewater are typically less than 5 counts/100 mL. Whilst slightly higher levels of faecal coliform are found in late summer and winter months, evidence of seasonality in faecal coliform concentrations is weak. This indicates no markedly greater potential for faecal contamination in the receiving coastal environment during the summer bathing season in relation to the microbiological faecal indicator bacteria quality associated with the discharged effluent from NPWWTP.

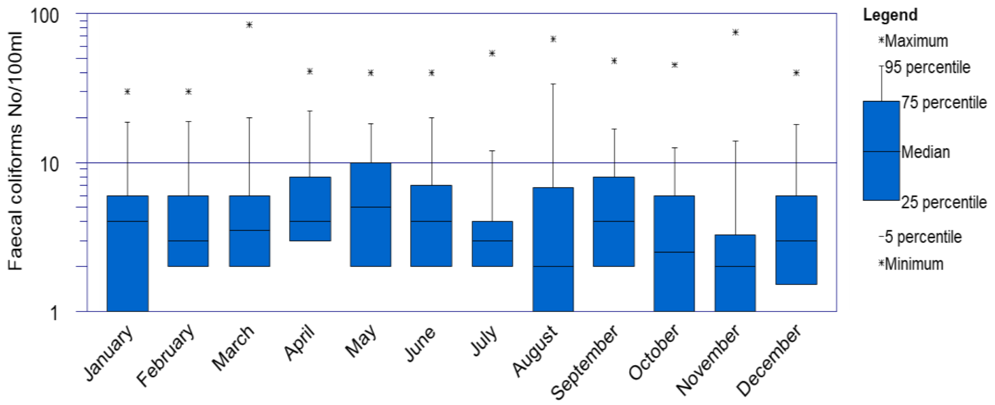

Figure 3-5: Seasonal (monthly) faecal coliform concentration using data for 2017 - 2022 calendar years. Non-censored data. Note log_{10}-scale on y axis.

Inter-annual variability as illustrated in Figure 3-6 is limited, as shown by the inter-quartile distribution (25%ile-75%ile) with concentrations of faecal coliforms in disinfected effluent ranging between 1 and 10 faecal coliforms/100 mL. Annual median values range between 1 and 4 faecal coliforms/100 mL.

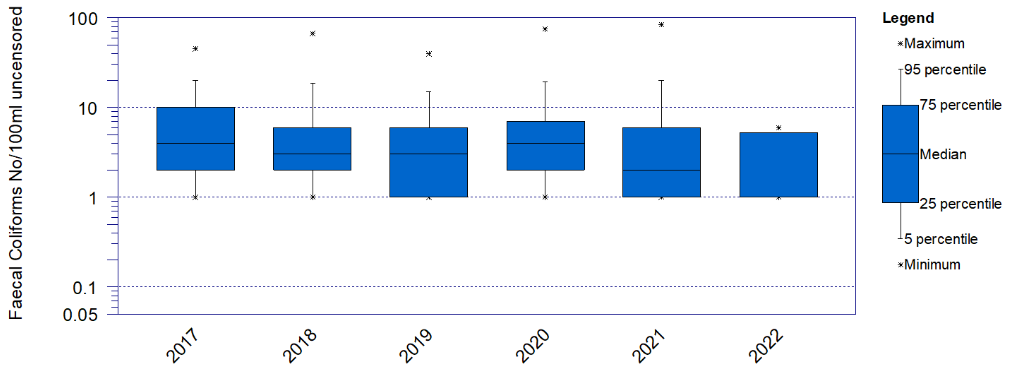

Figure 3-6: Annual summary of FIB (faecal coliform) in disinfected effluent. Note data for 2022 limited to information for January only. Non-censored data only. Note log_{10}-scale on y axis.

Annual 95th percentile concentration values for faecal coliforms are summarised in Table 3-1. Only 5 samples at most were analysed annually for enterococci so data are insufficient for comparison with microbiological assessment category thresholds as defined by the MfE/MoH (2003) guidelines for marine recreational waters (Ministry for the Environment and Ministry of Health, 2003) (Table 3-1).

There are however, faecal coliform guidelines in MfE/MoH (2003) for recreational shellfish harvesting which stipulate a median level of faecal coliforms not exceeding 14 MPN/100 mL of marine water over the shellfish gathering season and not more than 10% of samples to exceed 43 MPN/100 mL. Figure 3-5 and Figure 3-6 show that monthly and annual median levels of faecal coliforms in the disinfected effluent were consistently lower than 14 MPN/100 mL. However, compliance with these shellfish guidelines does not guarantee that shellfish harvested from waters of this FIB microbiological quality will be safe to eat.

Table 3-1: FIB concentration in NPWWTP disinfected effluent.

Year	Faecal coliforms	Enterococci	
	95th percentile concentration[10] CFU / 100 mL	No. samples	Concentration range CFU/100 mL
2017	20	1	<1
2018	18	4	<1 -5
2019	15	3	<1 -5
2020	19	5	<1 -3
2021	20	5	<1-10
2022	(insufficient data)		

3.2.2 Norovirus

Norovirus analysis of influent, clarified effluent and final treated effluent is undertaken to determine efficacy of secondary biological treatment and clarification for norovirus reduction under a range of influent concentrations and to assist confirmation that disinfection is being achieved.

Influent and effluent from NPWWTP were sampled on 14 occasions post upgrade, from 31/7/2013 to 1/11/2021. Final effluent samples were taken after treatment with sodium hypochlorite. Composited samples[11] were also collected from clarifier treated wastewater on 8 occasions from 7/11/2017.

Norovirus data for the NPWWTP have been evaluated assuming the date-matched influent and effluent data are related. Clarifier and effluent data have multiple censored thresholds in the dataset (e.g. <1, <13, <50 gc/L). Censored values comprise 37.5% and 12.5% for clarifier GI and GII whilst 71.4% and 42.9% of GI and GII values are censored for the effluent dataset. A summary of the data for influent, clarified effluent and treated (disinfected) effluent is provided in Table A-4.

Data available for quantification of norovirus genotypes GI and GII and removal efficiency is summarised in Figure 3-7 and Figure 3-8. The concentration of norovirus genogroup GII is typically higher than that of GI in both influent and treated wastewaters, consistent with findings from other studies, for example Montazeri et al. (2015).

[10] Percentiles calculated using the Hazen method as recommended in MfE/MoH (2003) Microbiological Recreational Water Quality guidelines but found to be the same as for Excel calculated values.

[11] Grab samples were collected from all 3 clarifiers and composited as follows: three litres were collected from each clarifier in turn and transferred directly to a 10 L sample container. The clarified sample was taken from the channel just prior to the liquid entering the launders box (Kate Giles, NPDC, pers comm).

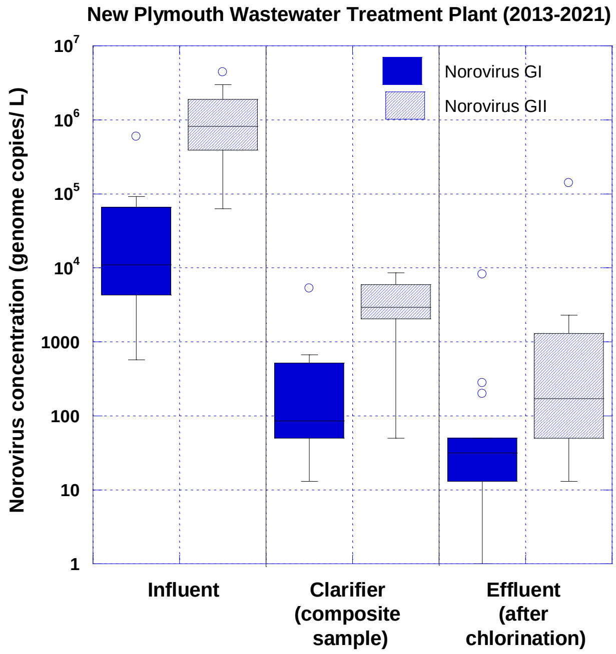

Figure 3-7: Range of norovirus concentrations in influent and effluent wastewaters from the New Plymouth Wastewater Treatment Plant. Data from 31/7/2013 to 1/11/2021; censored data included.

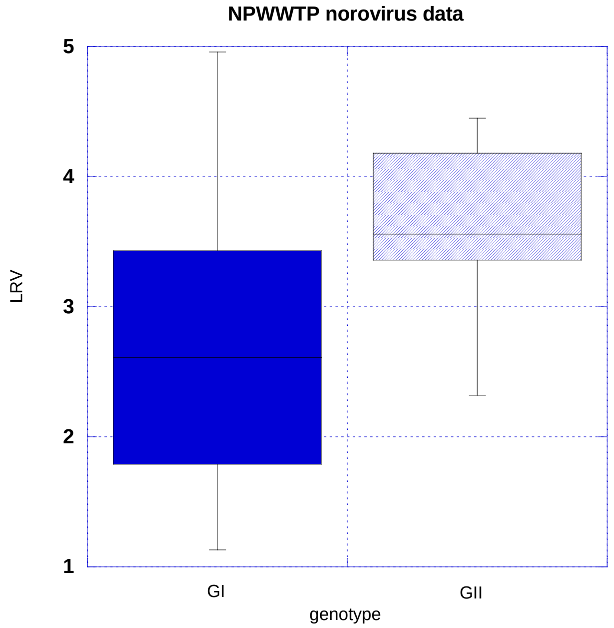

Figure 3-8: Norovirus reduction (log_{10} reduction values LRV) during wastewater treatment at NPWWTP. Data from 13 sampling occasions (9/6/2014-1/11/2021). LRVs calculated for GI and GII removal between influent and treated effluent post chlorination based on censored and non-censured data. Log reduction values (LRVs) measures microbial reduction achieved, indicating effectiveness of treatment in reducing microorganisms by powers of 10.

From the results in Figure 3-7 and Figure 3-8, the following can be inferred:

Influent

Norovirus can exhibit extreme variability, with concentrations in the New Plymouth influent ranging from 10^2 to 10^5 genome copies/L for GI (2.8-5.8 $\log_{10}$ gc/L) and 10^4 to 10^6 gc/L for GII (4.8-6.6 $\log_{10}$ gc/L) (Figure 3-7).

While norovirus was detected in influent wastewaters year-round, concentrations of GI and GII appear to be higher during autumn months (Mar – May, Figure A-6) and likely reflect the strongly seasonal norovirus related contributing population gastroenteritis rates observed during cooler months (Mounts et al. 2000).

The NPWWTP influent results appear consistently higher by an order of magnitude than influent concentrations for ten New Zealand WWTP reported by Hewitt et al., (2011) of 2.1-4.6 $\log_{10}$ GI gc/L and 2.2-5.5 $\log_{10}$ GII gc/L. Slightly elevated levels in New Plymouth influent may reflect undetected outbreaks of norovirus infection in the local community.

Genome concentrations of norovirus GII appear to be consistently higher than GI over time (Figure A-5) and throughout the WWTP with influent (and treated effluent) genome concentrations of GII around 2 $\log_{10}$ higher than GI (Figure 3-7).

Effluent

Standard wastewater treatment (excluding disinfection) is somewhat ineffective in removing norovirus, as indicated by the relatively high concentrations (>1000 gc/L) in the clarifier wastewater (Figure 3-7). This is in agreement with the review of influent and effluent norovirus in raw and treated (prior to disinfection) for the ten New Zealand wastewater treatment plants on three occasions over a summer (Hewitt et al. 2011). However, this assessment is precautionary, as it considers the infectivity of the influent norovirus is unaffected by the activated sludge process. This cannot be easily checked because norovirus is unable to be cultured but can only be assayed using molecular methods incapable of distinguishing viable from inactivated virions.

Chlorine disinfection appears to be slightly effective in reducing norovirus concentrations further, with effluent levels typically reduced to around 10^2 gc/L (Figure 3-7). On one occasion (31/7/2013) elevated genome concentrations of norovirus GI and GII by up to 2 orders of magnitude were detected in the effluent.

Fluctuations in influent and effluent norovirus concentrations appear to be influenced by flow variability, as indicated by lower influent and effluent concentrations of GI and GII during periods of increased inflow and outflow as seen in Figure A-8. This is likely attributable to dilution resulting from wet-weather flows. The limited available data does not provide any evidence to suggest that norovirus removal is reduced during periods of high flows within the flow range recorded in Figure A-9.

During normal WWTP operation, norovirus in treated NPWWTP effluent can at times be relatively low, as indicated by the high frequency of censored values <50 gc/L for GI (71%) and GII (43%) in disinfected effluent samples (Table A-4). Effluent concentrations based on uncensored data indicate GI and GII are reduced to median concentrations of around 2×10^2 gc/L and 1×10^3 gc/L in tertiary treated effluent respectively.

Monitoring data under normal flow operating conditions (9/6/2014 – 1/11/2021) indicate an average norovirus removal performance of 1.8 $\log_{10}$ GI and 2.5 $\log_{10}$ GII for secondary treatment prior to disinfection and 2.7 $\log_{10}$ GI and 3.6 $\log_{10}$ GII for final effluent post chlorination[12] when censored data is included. However, it is noteworthy that higher removal rates are likely when using censored data compared to non-censored data. Greater log removal was observed for GII than for GI (Figure 3-8) consistent with findings from other studies (Montazeri et al. 2015).

It is evident from the data that the WWTP does, at times, discharge some Norovirus into the marine environment from the WWTP throughout the year. However, there is very limited information on concentrations of norovirus discharged during summer months when recreational exposure is greatest.

During peak wet-weather flows and bypass events, the efficacy of chlorine disinfection of the effluent may be somewhat compromised. Bypass flow will not have passed through the full treatment process and the effectiveness of chlorination is impacted by elevated concentrations of ammoniacal nitrogen in the effluent (EPA 1999). For bypass flows at NPWWTP, the dosage of hypochlorite is adjusted to compensate for higher Total Suspended Solids (TSS) concentrations to ensure the effectiveness of Total Available Chlorine for pathogen inactivation. However, existing norovirus data is insufficient to determine the influence of bypass flows on treatment performance and the microbiological impact of blending primary effluent flow (exceeding secondary treatment capacity) with secondary effluent prior to disinfection and discharge.

3.3 Impact of wastewater discharge on receiving waters

3.3.1 Faecal indicator bacteria

As noted previously, a slight increase in the volume of wastewater discharged over the period 2018-2022 (~5%) was evident (Figure 3-3) and effluent FIB concentrations were relatively constant (Figure 3-5 and Figure 3-6). Consequently, the flux or instantaneous load[13] has remained constant over this period as well, as indicated by Figure 3-9. The flux or load estimates provide an indication of the likely impact on receiving waters. The median daily flux of faecal coliforms discharged ranged from 6×10^{8} /day to 8×10^{8} /day.

Figure 3-10 indicates that there is some seasonal variation in wastewater treatment efficiency throughout the year. Figure 3-2 showed higher wastewater volumes discharged in the winter months (June – August), whereas Figure 3-10 indicates that the flux or load of faecal coliform peaks slightly earlier, occurring during the late autumn-early winter months of April to June and again in December to January. This suggests that a higher quantity of indicator bacteria is released during the season when recreational users are exposed to risks. Whilst exposure to higher levels of indicator bacteria implies increased health risk exposure, this observation is limited, as it relates specifically to faecal coliforms as indicators of the likely presence of pathogens. The relatively consistent concentration of faecal coliforms in the discharged wastewater (Figure 3-5) indicates a consistent treatment efficacy of the NPWWTP in mitigating the potential hazards associated with faecal microbial contaminants. It also highlights the importance of ongoing microbiological monitoring to ensure continued environmental and public health protection.

[12] Calculated from the average of $\log_{10}$ reduction values for influent and effluent concentration data matched for date.
[13] Flux or instantaneous load is derived by combining the daily average discharge value with the FIB concentration for the day to provide a load of FIB (number per unit of time).

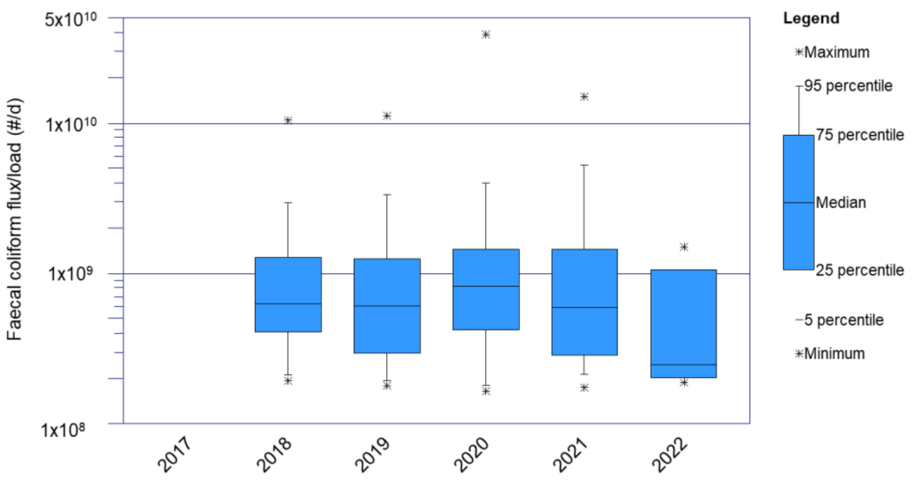

Figure 3-9: Annual summary of calculated daily wastewater faecal coliform flux or instantaneous load (Aug 2018 to Jan 2022 inclusive). Note y-axis is $\log_{10}$ scale and 2022 year is incomplete.

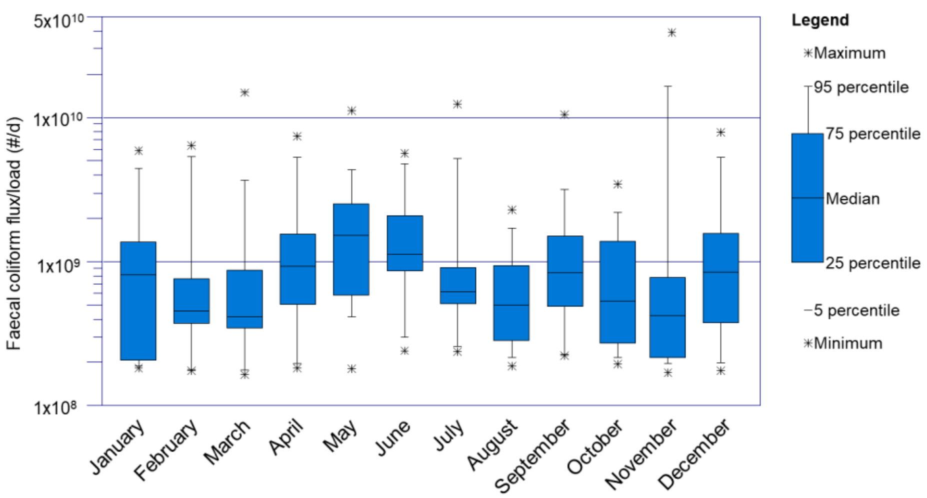

Figure 3-10: Seasonally (monthly) summary of calculated daily wastewater faecal coliform instantaneous load, Aug 2018 - Jan 2022 inclusive. Note y-axis is $\log_{10}$ scale.

3.3.2 Norovirus in shellfish

Norovirus is a principal cause of gastroenteritis associated with shellfish consumption (Westrell et al. 2010) and has been associated with several outbreaks associated with recreationally harvested shellfish in New Zealand (Hewitt 2019).

The link between wastewater discharge and the contamination of bivalve molluscan shellfish (BMS) is well established (Flannery et al. 2012). Contamination occurs because filter feeding shellfish such as green lipped mussels have the capacity to accumulate contaminants in their tissue over time. Consequently, they can serve as biomonitors to evaluate the contaminant load at a particular site.

Naturally occurring green lipped mussels were collected from 4 low shore sites, each with varying degrees of influence from the NPWWTP discharge outfall: Waiwhakaiho Reef (SEA902015), Bell Block (SEA902001), and on one occasion from East End Beach (SEA902038 – Arakaitai Reef) and Kaweroa Reef (SEA902055) and a control site at Oakura (SEA903020).

Results from shellfish sampling for norovirus contamination at two locations north and south of the NPWWTP outfall (Bell Block and Waiwhakaiho Reef respectively) are shown in Table 3-2 for sampling occasions where normal operation (post upgrade) were included (from 15 June 2014 onwards). Refer to Figure B-1 and Figure 3-16 for location of sites relative to the outfall discharging treated wastewater from NPWWTP.

Table 3-2: Detection of norovirus (GI or GII genogroup) in green lipped mussel flesh from samples collected north or south of the NPWWTP outfall. Results from sampling occasions during normal operating conditions and post-upgrade of NPWWTP (June 2014 - July 2022).

Site	No. sampling occasions (No. of samples)	Norovirus[a] positive samples	% positive samples containing Norovirus
Bell Block	13	3	23
Waiwhakaiho Reef	14	8	57
East End Beach[b]	1	1	
Kaweroa Reef[b]	1	0	
Oakura (control site)	1	0	

a: Sampling occasion positive for either norovirus GI or GII; b: sampling at these sites undertaken as part of a separate water quality investigation.

Mussels sampled from Waiwhakaiho Reef, 500 m southwest of the WWTP outfall, were more frequently contaminated (57% positive sampling occasions) than mussels sampled from the Bell Block site (23% positive sampling occasions) when the NPWWTP was operating under normal flow conditions (Table 3-2, Table B-1). A higher prevalence of contamination in shellfish closest to the WWTP outfall where concentration of norovirus is likely to be highest is consistent with dilution increasing with distance from the outfall. Similar findings have been reported in other studies in New Zealand, with highest levels of contamination in shellfish found at sites closest to WWTP outfalls (Greening 2006), since the concentration in shellfish corelates with the concentration in the surrounding water (Flannery et al. 2012).

In contaminated mussels, norovirus genogroup GII was more commonly detected than GI at both Bell Block and Waiwhakaiho Reef Figure 3-11. In general, 64% of sampling occasions were positive for norovirus GII in mussel flesh in comparison to 36% positive sampling occasions for GI. Greater prevalence of GII in mussels agrees with other studies in New Zealand where GII has been more frequently reported in shellfish (Greening and Lewis 2007), and for the NPWWTP study, likely reflects the generally higher concentrations of GII in treated effluent compared to GI. Prevalence of norovirus GII in Waiwhakaiho reef collected mussels was also greatest in autumn (Figure 3-12), coinciding with generally higher median GII concentrations in the treated effluent, although we note the overall low number of positive samples this is based on.

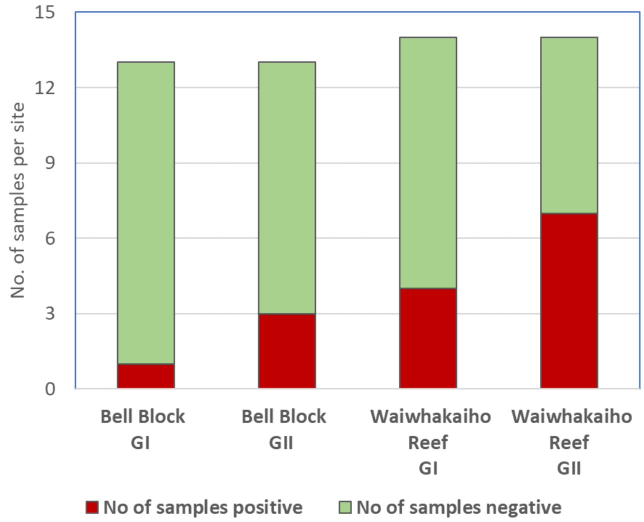

Figure 3-11: Detection of norovirus genogroups GI and GII in shellfish from Waiwhakaiho Reef (500 m SW outfall) and Bell Block (2014-2022).

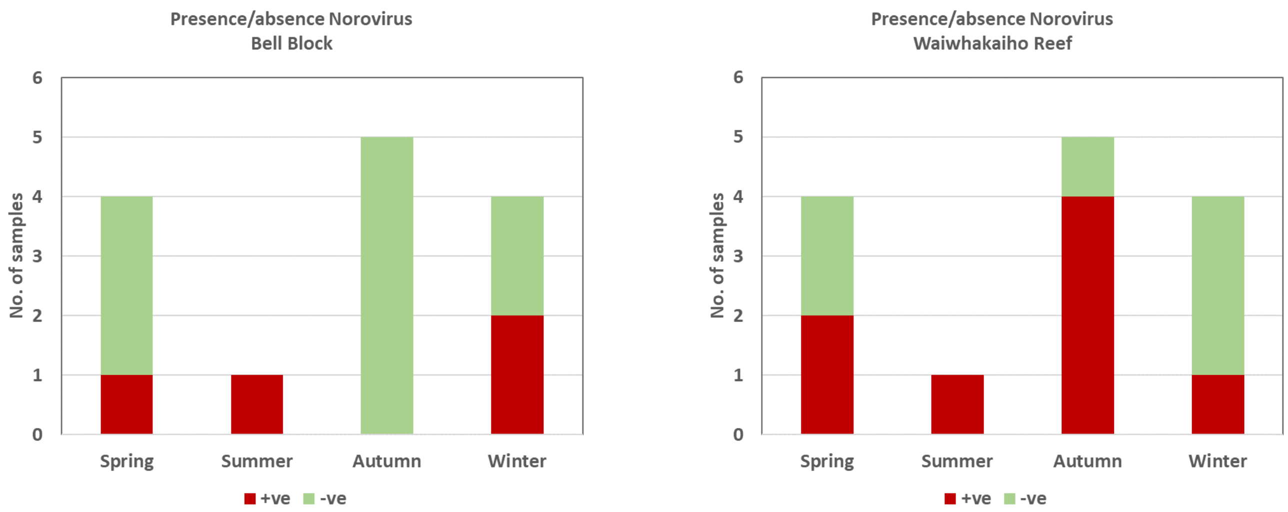

Figure 3-12: Seasonal prevalence of norovirus in green lipped mussels collected from Bell Block or Waiwhakaiho Reef (2014-2022).

When detected in shellfish, levels of norovirus GI or GII were often below levels of quantification (LOQ of 80 genome copies per gram) during normal flow operation– a characteristic reported in other studies particularly for GI (Doré et al. 2010). But on the occasion of bypass flow (20/8/2013), higher levels of contamination were found at both Bell Block (110 GII gc/g) and extremely high levels at Waiwhakaiho Reef (17,000 GII gc/g). Low contamination levels were also found in mussels further south at Oakura reference site on that sampling occasion.

Levels of quantified contamination in mussels collected during normal flow operation extended up to 600 gc/g at Waiwhakaiho Reef and 400 gc/g on a separate occasion at Bell Block. Studies have suggested that many of the observed outbreaks of illness are associated with relatively high levels of norovirus (>1000 gc/g), though outbreaks with levels of 170 gc/g have also been reported (McLeod et al. 2017). No New Zealand commercially harvested BMS samples associated with a notified norovirus outbreak contained levels of norovirus >1000 gc/g guts (Hewitt et al. 2019) indicating lower levels of contamination does not imply safety and could still pose a risk to consumers.

The median infectious dose (ID_{50}), the number of viruses required to make half the people in a sample infected, varies between 18 and 1015 genome copies (gc) depending on whether virus particles are aggregated or not (Teunis et al 2008). Generally, it is impossible to assess the virus's aggregation state. So the public health significance of shellfish containing low levels of norovirus (less than 1000 gc/g,) is not clear. Sporadic cases of infection or illness may be caused by shellfish with low norovirus levels, particularly for more susceptible individuals (Thebault et al. 2013). For commercial shellfish, the European Union has proposed a norovirus standard of 200 gc/g, which is the sum of the two norovirus genogroups (GI and GII) (Hassard et al. 2017). In practice this would mean that the measured values of GI and GII would both be required to be below the level of quantification (e.g., 80 gc/g in the NPWWTP study) to meet the standard.

Results from the 2023 QMRA indicate that an Individual's Illness risk from eating raw shellfish on any random day (under normal flow conditions) is around 5% for Bell Block and higher risks of around 7% for shellfish harvested from Waiwhakaiho Reef. Elevated health risks for individuals consuming raw shellfish harvested from Waiwhakaiho Reef is suggested from shellfish data with norovirus contamination occurring more often and at higher levels compared to mussels harvested from Bell Block. However, it is important to interpret this information cautiously, recognising that while norovirus has been detected in mussels, the data is limited in establishing the risk at one site as definitively greater than the risk for the other site.

3.4 Recreational water quality

Faecal indicator bacteria have been monitored at coastal sites around the NPWWTP outfall to assess shoreline contamination. Water quality sampling occurs in accordance with the general requirements of the MfE/MoH (2003) recreational water quality guidelines, involving weekly collection during the bathing season, typically during November to March. Sampling provides approximately 20 samples per bathing season. Sites are sampled every other year, although duration of sampling varied for each specific site.

Microbiological water quality data from 10 shoreline locations including two sites east and one site west of the outfall were used to assess recreational water quality along the coastline and potential adverse effects of the marine outfall on coastal bathing water quality. A site in the lower reaches of the Waiwhakaiho River (at Lake Rotomanu) was also included to assess the potential impact of the river downstream on coastal bathing water quality. Sites for analysis were selected based on sites used for the 2023 QMRA. The location of the QMRA sites (W1-18; E1-12), shoreline monitoring sites and shellfish sampling sites are shown in Figure 3-16.

3.4.1 Recreational risk

Enterococci is the preferred indicator to assess the safety of marine waters for contact recreation. Guideline values for enterococci concentration in coastal bathing waters aim to keep illness risks associated with recreational use to less than around 2%. Long term surveillance of water quality is used to grade bathing water quality. Ideally assessments would make use of 100 data points (representing an approximately 5-year sampling period). However, in this instance only a little more than 60 data were available for five sites and the remaining sites had fewer than 30 data points. A statistical summary of the shoreline monitoring data is provided in Table C-2. All coastal sites had a proportion of enterococci results below detection limits of 1 CFU/100 mL (<2021) or less than 10 MPN/100 mL (>2021). These censored values have been coded as half the detection limit value for the preparation of figures.

The data available for the bathing seasons are summarised in Figure 3-13 and Figure 3-14 for the enterococci data.

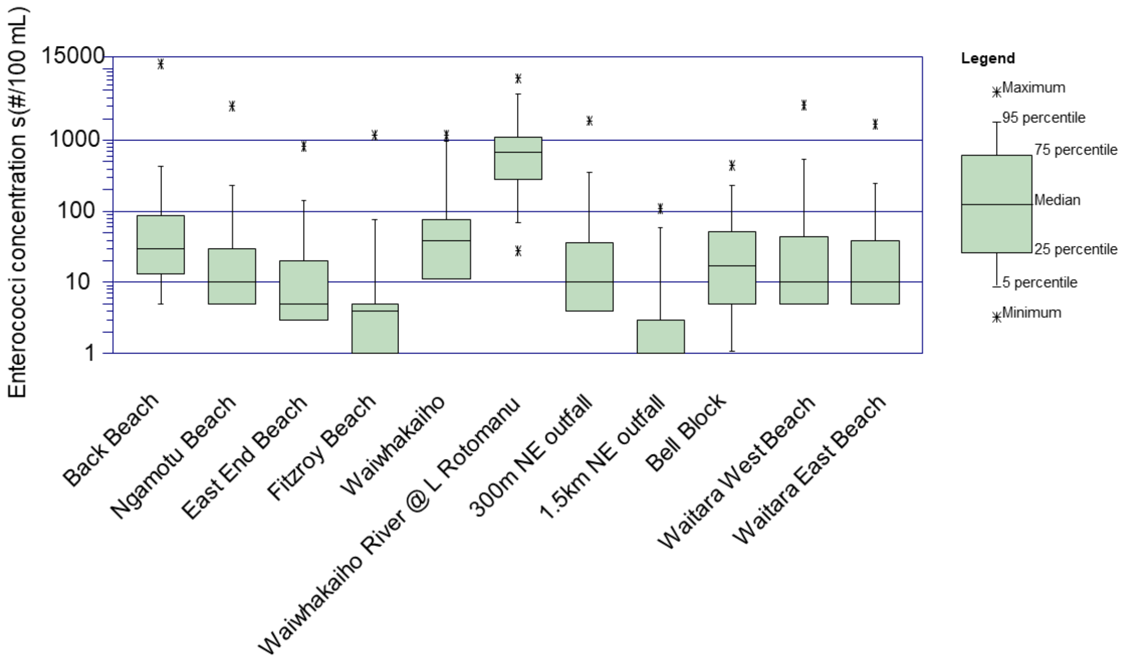

Figure 3-13: Recreational water quality data for bathing seasons (2013 - 2022). Note y-axis has $\log_{10}$ scale.

Figure 3-13 and Figure 3-14 suggest a decline in water quality with wider distribution south-westwards along the coastline from Fitzroy Beach and north-eastwards towards Bell Block, potentially indicating the impact of urban runoff. Water quality at sites near to the outfall (W2: Waiwhakaiho and E1: 300 m NE) most likely reflects the influence of the Waiwhakaiho River. Median concentrations of enterococci in the treated wastewater are notably low from the limited dataset (around 3 counts/100 mL) in contrast to the enterococci concentrations in the Waiwhakaiho River of around 1000 counts/100 mL.

Potential health risks from each site are compared in Figure 3-14 with three enterococci threshold concentration values related to estimated risk for contact recreation in the NZ Recreational Water Quality guidelines. These thresholds are defined for the Microbiologically Assessment Categories (MAC) for marine waters based on 95th percentiles and are used for long-term grading of marine recreational water quality. Ideally 100 datapoint should be used in deriving the 95th percentile (MfE/MoH 2003) (representing monitoring over approximately 5 bathing seasons)[14]. The concentration thresholds and associated risks are explained in Table 3-3.

[14] In this analysis, 2 bathing seasons used for Waiwhakaiho and Waikwhakaiho River, 4 bathing seasons for 300 m and 1/5 km NE Outfall, Bell Block, 5 for Back Beach, and 6 for Ngamotu, East End, Fitzroy and Waitara West and East. Refer to Table C-3 for bathing season data available for each site.

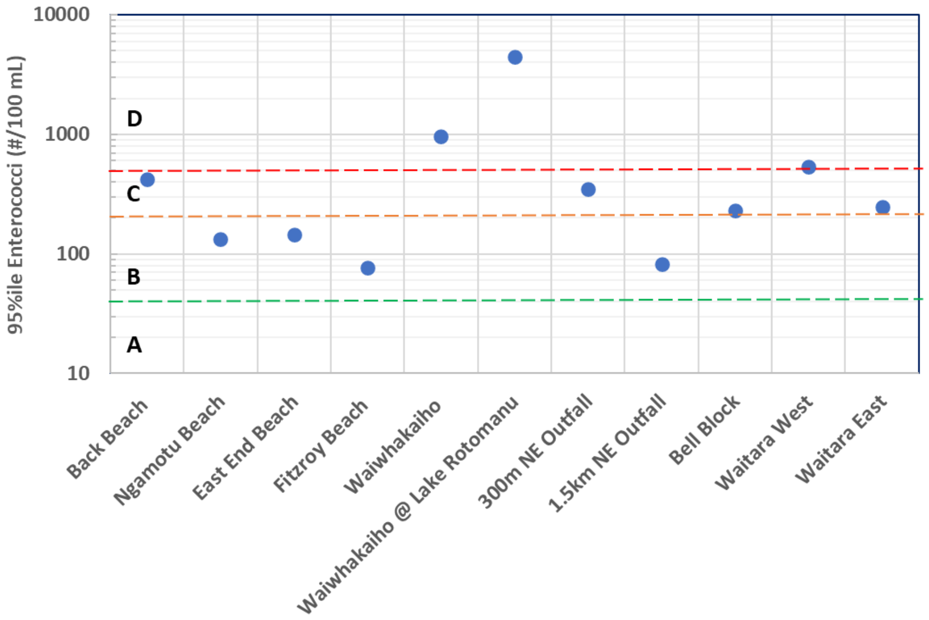

Figure 3-14: Recreational Water Quality, 2013-2022 expressed in terms of the 95th percentile for enterococci concentrations. Note y-axis is $\log_{10}$ scale. A, B, C and D refer to guideline values in relation to risk thresholds in the MfE/MoH (2003) Recreational Water Quality guidelines and are distinguished by dashed lines.

Table 3-3: Risks associated with 95th percentile enterococci concentrations. From MfE/MoH (2003) guidelines, Table H1 and associated text. "GI" is gastrointestinal illness, and "AFRI" is Acute Febrile Respiratory Illness.

Category (MAC)	Threshold value (95th percentile value of enterococci/100mL)	Estimated Risk (%)		Commentary
		GI	AFRI	
A	≤ 40	< 1	<0.3	Considered to have a very high recreational water quality likely to cause fewer than 1 case of gastrointestinal illness/100 exposures (≤1% IIR) and fewer than 1 case of AFRI/50 exposures
B	41 - 200	1 - 5	0.3-1.9	Considered to have high recreational water quality, likely to cause up to 5 cases of gastrointestinal illness/100 exposures (>1% to ≤5% IIR) and 1.9% AFRI
C	201 - 500	5 - 10	1.9-3.9	Represents a risk of up to 10% for gastrointestinal illness and 3.9% AFRI
D	>500	>10	>3.9	Represents a risk of more than 10% for gastrointestinal illness (>10% IIR) and 3.9% AFRI

Most of the sites are either “B” or “C” graded, indicating a gastrointestinal illness risk of greater than 1% - a level of risk higher than estimated in the 2023 QMRA for normal flow operation. Recreational water quality data suggest health risk varies spatially, with greatest risk at sites close to the outfall (within 500 m SW and 300 m NE) and within close proximity to the mouth of the Waiwhakaiho River.

Enterococci concentrations decrease with distance from the outfall with dilution and inactivation of FIB likely reducing concentrations with wider distribution along the coastline.

However, the data also suggest a slight increase in enterococci concentration and associated risk west and east beyond the outfall location at "urban" beach sites such as Ngamotu (W16) and Back Beach (W18) and Waitara beaches. A similar spatial pattern in recreational risk at Base (normal flow) conditions is shown in Figure 6.1 of the 2023 QMRA, with greatest risk estimated around the outfall site, with a decrease in risk west and east of the outfall but a slight risk increase further SW along the coastline beyond site W9.

Whilst the source of elevated enterococci at each of the sites is not known, the urban sites are likely to be impacted by sources from the adjacent conurbation as well as from other sources. The modelling work undertaken by MetOcean indicates that contaminants can be transported to both the west and east of the outfall. The FIB could originate from the NPWWTP as a reasonably consistent load of FIB are discharged into the inshore waters (Figure 3-9), some of which may impinge on sites along the coastline. However, the load of FIB discharged from the Waiwhakaiho River would be markedly greater than that from the NPWWTP. Other potential sources such as avian inputs from seagulls congregating on the intertidal reef at Waihwakaiho would also contribute to bacterial contamination (McElroy 2021).

3.4.2 Recreational shellfish harvesting

Recreational shellfish gathering guidelines are outlined for bacterial concentration (faecal coliforms) in harvesting waters in the MfE/MoH (2003) guidelines. Recommendations are for a median faecal coliform concentration of ≤14 FC /100 mL and no more than 10% of samples should exceed 43 FC/100 mL. There are no risk thresholds associated with these guidelines.

Data is available for faecal coliforms at recreational water quality monitoring sites for shoreline waters, but only extends over the summer months (November to March/April).

Faecal coliform concentrations varied spatially (Figure 3-15) and showed similar spatial trends as for enterococci in Figure 3-13. Median faecal coliform concentrations were generally below 10 /100 mL for all sites, except Back Beach (W18) and Waiwhakaiho Reef (~W2). However, the proportion of samples exceeding 43 FC/100 mL were greater than 10% for all sites, except Fitzroy Beach (W6) and 300 m NE (E1) and 1.5 km NE (E3) of the outfall, indicating that general suitability for recreational shellfish harvesting was limited to these three sites as only these sites met both microbial water quality criteria for shellfish harvesting as recommended by MfE/MoH (2003) (median ≤ 14 FC/100 mL, 90% of samples <43 FC/100 mL).

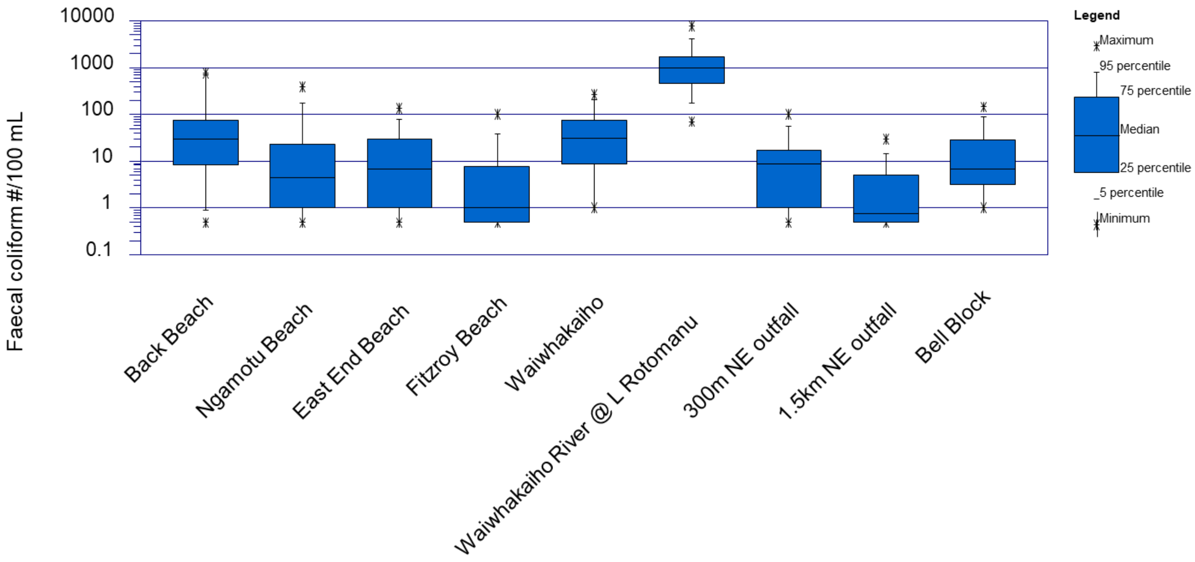

Figure 3-15: Faecal coliform concentration (2013-2022). Note y-axis has log_{10} scale.

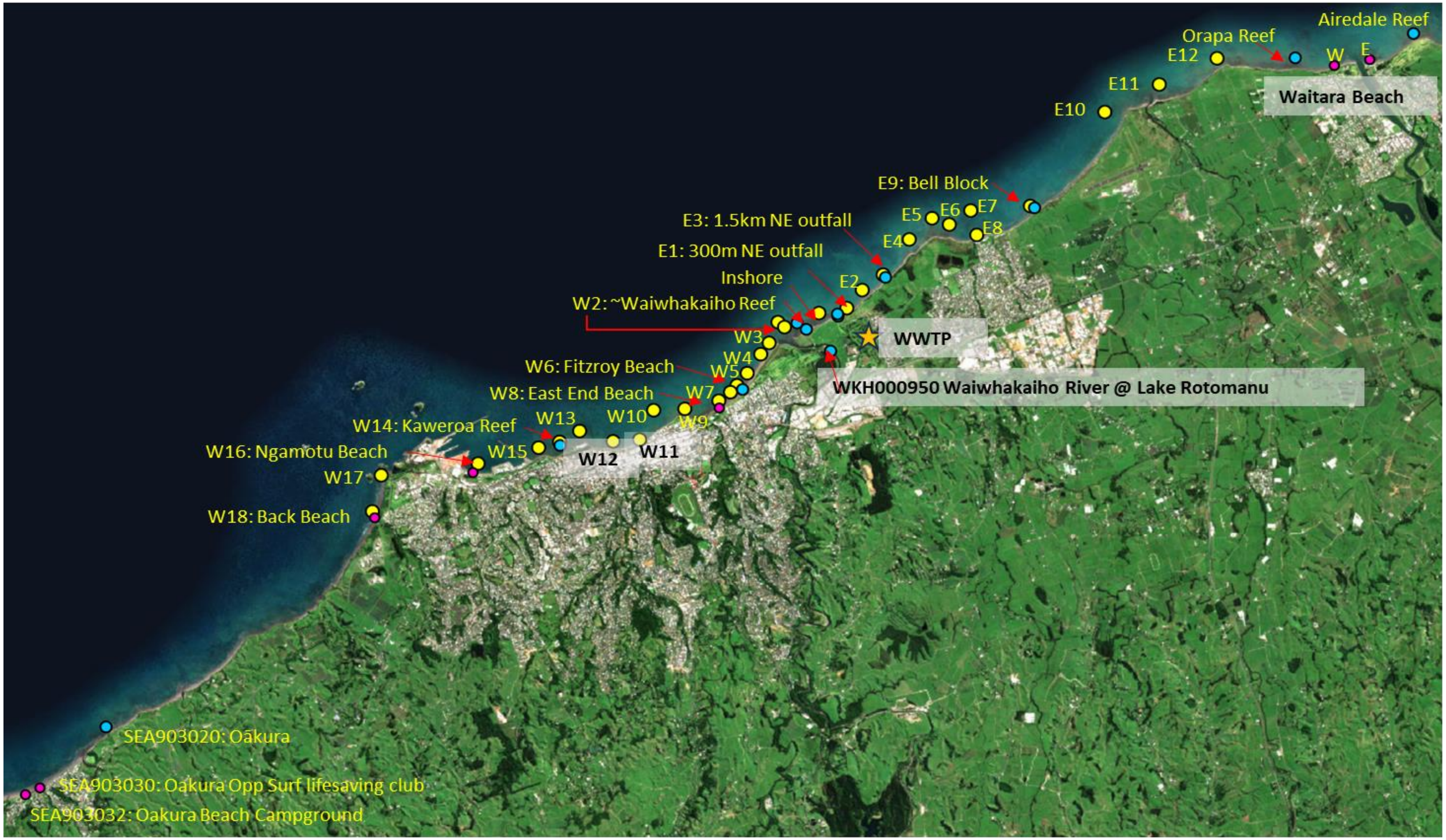

Figure 3-16: Spatial mapping of sites used for QMRA (E1-E12; W1-W18), recreational water quality monitoring and shellfish monitoring for norovirus.

4 Summary

From the results in Section 3, the following inferences can be made:

4.1 NPWWTP characteristics

4.1.1 Discharge volume and microbial composition

There is evidence of a slight increasing trend in annual daily average discharge volume over the period assessed. There is also evidence of seasonality with higher wastewater discharge volume in winter.

There is little indication of deterioration in treatment performance (i.e. increase in FIB concentration or norovirus) as a consequence of increase in wastewater discharge rate (Figure A-4 and Figure A-8 respectively) on an annual basis. There is weak evidence of seasonality, with slightly higher levels of faecal coliforms in treated effluent in late autumn and early winter months but no evidence for seasonal effect of treatment efficacy over the summer bathing season (Figure 3-5). There was no evidence of an annual increase in daily average FIB load discharged from the NPWTTP, but a seasonal trend was apparent with median daily FIB flux or instantaneous load peaking in late autumn months. FIB flux also increased in summer months (probably as a consequence of increased influent load to the WWTP as the local population increases over the holiday period) indicating a potential for higher environmental loading from the NPWWTP during the summer.

Wastewater monitoring indicates a consistent microbiological quality of disinfected treated effluent with low faecal indicator bacteria levels, typically below 10 counts/100 mL, and low levels of norovirus generally below 1000 genome copies/L.

Norovirus genogroups GI and GII are continuously detected in influent wastewater demonstrating both genotypes circulating in the local population throughout the year.

Influent norovirus concentrations appear consistently higher by an order of magnitude than influent concentrations for ten New Zealand WWTP. Elevated concentrations of norovirus GI and GII found in NPWWTP influent wastewaters were considered in the 2023 QMRA and reflected in the order of magnitude increase in median influent virus concentration to 10^5 gc/L, from the 10^4 gc/L value used in the 2012 QMRA Report.

Influent concentrations of norovirus GI and GII were reduced during wastewater treatment to median concentrations of <13 and <50 gc/L in treated effluent respectively, indicating consistent removal.

For normal WWTP operation, a conservative estimate of removal performance based on uncensored values indicate a median Log Reduction Value (LRV) for norovirus of 2.5 $\log_{10}$ GI (range 1.5-3.1 $\log_{10}$ units) and 3.4 $\log_{10}$ GII (range 2.3-3.6 $\log_{10}$ units) after tertiary treatment.

Whilst norovirus is removed relatively effectively during wastewater treatment, treated effluent may still contain some norovirus (up to 10^2 GI gc/L and 10^3/L GII). However, the infectiousness of norovirus in the effluent is not known due to limitations of molecular methodology for detection and quantitation. Results may therefore overestimate infectious virus present in the final effluent and thus underestimate the reduction of viable viruses.

4.2 Impact on receiving environment

Recreational water quality monitoring of shoreline sites westward and eastward of the outfall location indicate some spatial variation. Seasonal median and 95th percentile enterococci concentrations suggest:

- A decline in water quality south/west from Site W6 (Fitzroy Beach) and north/east from site E3 (1.5km NE from outfall) along the coastline as indicated by an increase in enterococci concentrations,
- Higher FIB concentrations in areas:
  - Likely to be impacted by urban stormwater runoff, or,
  - In the path of contaminants transported along the coastline from other sources such as the Waiwhakaiho River.

Monitoring of the Waiwhakaiho River showed dry weather median FIB concentrations two orders of magnitude higher than the treated effluent. The river discharge is likely to have a greater impact on FIB water quality in the coastal area than the NPWWTP discharge, particularly during rainfall events when loading in the river is anticipated to be much greater.

Evidence of norovirus contamination of shellfish, although sporadic, provides evidence of adverse effects in shoreline waters. The prevalence of contamination in green lipped mussels was related to the proximity to the outfall, with greatest frequency of contamination occurring within 500 m SW from the outfall. When detected in mussels, norovirus GI or GII was often below the level of quantitation levels (≤ 80 genome copies/g gut tissue) – a characteristic reported in other studies particularly for GI (Doré et al. 2010.). These levels are not consistent with those that have reportedly caused illness in consumers. However elevated concentrations of norovirus (>500 gc/g) were detected in mussels harvested from Waiwhakaiho Reef within 500 m SW from the outfall which would signify an elevated risk. There may also be occasions of moderate risk from sites further up the coast infrequently impacted by discharged treated effluent due to plume dilution as indicated by mussel contamination on occasions at Bell Block.

There is evidence of probable impact of the outfall on the microbiological contamination of filter feeding shellfish, thereby presenting health risks associated with recreational shellfish harvesting. NPDC reports that the development of the coastal walkway has resulted in increased recreational use by shellfish gatherers as a result of improved access.

At Waiwhakaiho Reef, shellfish were frequently contaminated with human norovirus, with significantly elevated levels detected after a bypass event. Although such events are infrequent, it's important to note that norovirus can persist in shellfish for at least 4 weeks (Greening 2006) and possibly up to 10 weeks post bioaccumulation (Hewitt et al. 2019). As a precautionary measure, it would be inadvisable to consume raw or partially cooked shellfish collected from Waiwhakaiho Reef for at least this period after a bypass event. Bell Block might be considered a low-risk site during normal operation of the WWTP, given the infrequent detection and low levels of norovirus contamination in mussels even during a Bypass event. However, a discussion is warranted to determine what level of risk is deemed tolerable in this context.

4.3 Recreational risk

Using the data summarised in Figure 3-14 and the risk thresholds defined in Table 3-3, the recreational water quality data collected in the preceding summer bathing periods suggest that for the sites nearest to the outfall:

- a >10% risk of GI illness and >3.9% AFRI illness exists for the Waiwhakaiho Reef site (~W2),
- a 5-10% GI illness and 1.9-3.9% AFRI illness risk exists for the site 300 m NE of the outfall (E1), and
- a 1-5% GI illness and 0.3-1.9% AFRI illness risk exists for the site 1.5 km NE of the outfall (Mangati E3).

The sites at 300 m NE and 1.5 km NE of the outfall are not commonly used for recreational bathing due to limited accessibility, but Waiwhakaiho Reef is a popular surfing area.

- For sites further SW along the coastline, typically a ≤5% GI illness risk and ≤1.9% AFRI illness risk exists.
- For sites further NE along the coastline a >5% GI illness and >1.9% AFRI illness risk exists.

These risks were estimated using fewer than 100 data points recommended by the MfE/MoH (2003) guidelines (collected over a five-year period). Risks apply to contact recreation, and are not infection but illness risks, which apply to normal circumstances. They do not apply when an epidemic/outbreak exists in the community.

Microbial water quality for the recreational sites was collected during dry weather and thus are independent of Bypass flows from NPWWTP which occur infrequently and over relatively short duration. Therefore, these risks can be considered indicative of the influence of general background activities that introduce faecal microbial contaminants into the New Plymouth coastal environment.

The recreational risks associated with sites SW and NE of the outfall reflect the impact of faecal contaminants from all sources and are larger than those average risks indicated by the 2023 QMRA. This outcome is consistent with QMRA estimates which provide the **incremental risk associated exclusively with the NPWWP discharge**, i.e., it does not account for other contaminant sources.

4.4 Shellfish consumption

Using the data summarised in Figure 3-15 and Table C-2, the water quality data collected in the preceding summer bathing periods suggest that for the sites nearest to the outfall:

- FIB water quality conditions at Waiwhakaiho Reef are unsuitable for recreational shellfish harvesting,
- FIB water quality conditions further NE along the coastline may be marginally suitable for shellfish harvesting.

FIB monitoring of the NPWWTP indicates effluent discharged is of a high quality (annual median daily concentration 1-4 FC/100 mL) indicating that with dilution and inactivation in the receiving environment, faecal coliforms in coastal waters are likely from other faecal sources impacting the coastal environment.

However, monitoring of green-lipped mussels at several sites indicates norovirus contamination and an adverse impact of wastewater discharge on shellfish associated health risk. Shellfish monitoring provided evidence that:

- at a potential impact site near to the outfall, mussels are frequently contaminated, but,
- contamination of mussels is less prevalent at a site further up the coastline and distant from the outfall,
- norovirus are often detected at sub LOQ levels in contaminated mussels under normal flow operations, and,
- for bypass flow events, greater contamination levels increase the exposure risk for shellfish consumption and are more widespread and distributed further along the coastline.

The observed prevalence and levels of norovirus contamination from the mussel monitoring align with the risk estimates in the QMRA, highlighting spatial variation in health risks. A high risk associated with shellfish consumption is identified at the site closest to the outfall discharge (Waiwhakaiho Reef, QMRA site W2) while lower potential risks are noted further away at Bell Block (E9) under present normal flow conditions. However, it is important to note that risks become elevated during Bypass events. The significance of Bypass flow on mussel contamination is particularly important and warrants further consideration. Enhanced risk assessment will be supported by modifications to the monitoring plan in 2022, incorporating the sampling and testing of mussel flesh for norovirus instigated by any bypass events (NPDC 2022).

Guidelines do not exist for virus levels in shellfish, though guideline values exist for *E. coli* levels in shellfish flesh gathered for commercial purposes of <230 *E. coli* per 100 g flesh[15]. Whilst concentrations of norovirus are generally low in mussels collected from two sites along the New Plymouth coastline, the risk is difficult to quantify as the evidence base is unclear as to whether low norovirus concentrations in shellfish represent a low risk of infection. The European Union has proposed commercial limits for norovirus (GI and GII combined) of 200 gc/g. Levels of norovirus GI and GII in New Plymouth mussels were typically above the detection limit but often below the LOQ of 80 gc/g simultaneously and would, in these instances, therefore meet proposed EU thresholds.

Whilst health risks associated with recreational shellfish gathering at reefs near the outfall and raw shellfish consumption might be considered low, recreational shellfish harvesting could still on occasion represent a risk, and consumption is not advisable.

[15] The microbiological limits outlined in the New Zealand Food Safety Authority Animal Products are for *E. coli* levels in shellfish, with <230 *E. coli* per 100 g flesh and intervalvular fluid approved for direct consumption.

5 Acknowledgements

We thank Amy Quattlebaum for facilitating the supply of data from NPDC, Kate Giles (TRC) for supply of recreational water quality and shellfish data, and Sanjay Wadhwa (NIWA) for spatial mapping of the various QMRA sites and monitoring sites for shellfish and shoreline water quality.

6 Glossary of abbreviations and terms

BMS	Bivalve Molluscan Shellfish. Filter feeding shellfish such as oysters, mussels, pipi, cockles
FIB	Faecal Indicator Bacteria
gc/L	Genome copies per litre
gc/g	Genome copies per gram
LOQ	Limit of Quantitation (80 genome copies/g shellfish gut for norovirus analysis)
MfE	Ministry for the Environment
MoH	Ministry of Health
NPDC	New Plymouth District Council
NPWWTP	New Plymouth Wastewater Treatment Plant
PCR	Polymerase Chain Reaction. Method for molecular detection of microorganisms e.g. viruses
QMRA	Quantitative Microbial Risk Assessment
RT-qPCR	Reverse Transcriptase - quantitative Polymerase Chain Reaction. Method for norovirus based on ISO 15216-2:2019

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Appendix A New Plymouth Wastewater Treatment Plant

A schematic of the New Plymouth Wastewater Treatment Plant, also known as the Waiwhakaiho Wastewater Treatment plant is shown in Figure A-1.

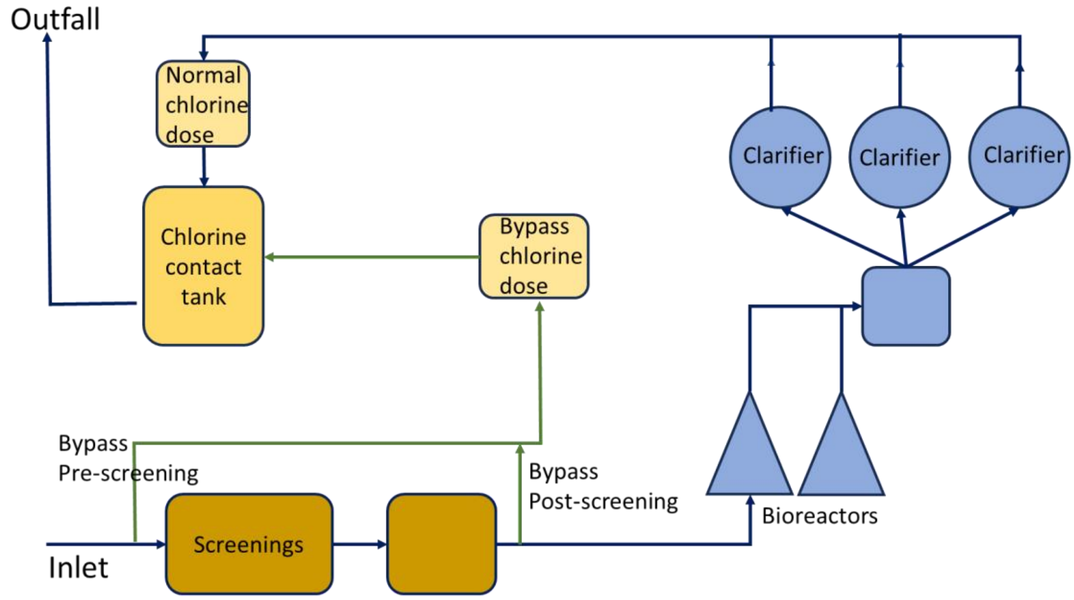

Figure A-1: Treatment train for wastewater treatment at the New Plymouth Wastewater Treatment Plant. Schematic based on a figure supplied by New Plymouth District Council.

The treatment train at NPWWTP includes preliminary treatment by screening out solids, a primary biological treatment process (extended activated sludge aeration in a “racetrack” or carrousel circulating channel), secondary clarification and tertiary disinfection using sodium hypochlorite to produce final treated effluent for discharge to the Tasman Sea via a marine outfall located 480 m offshore (Figure A-2). The aerated basins were upgraded in 2015 to what are now referred to as Bioreactors. Currently, the need to bypass flows arises temporarily with the need to take a Bioreactor offline for maintenance specifically to clean and replace the air diffusers. Typically, bypassing flows is not needed during an outage and although the consent permits bypass of up to 50% of the flow, in reality, flow bypass has only occurred once briefly for a few days during an outage a couple of years ago constituting 2% of the total flow over a 14-day period.[16] For bypass flows, the dosage of hypochlorite is adjusted to compensate for higher Total Suspended Solids (TSS) concentrations to ensure the effectiveness of Total Available Chlorine for pathogen inactivation. Maintaining the capability to bypass is required for future scenarios considering potential growth.

Treatment of sludge consists of dewatering the wasted activated sludge followed by thermal drying to produce Bioboost fertiliser.

[16] Information supplied by Suzanne Vennik, Kaiwhakahaere Whakapai Wai-para / Wastewater Treatment Plant Lead, NPDC

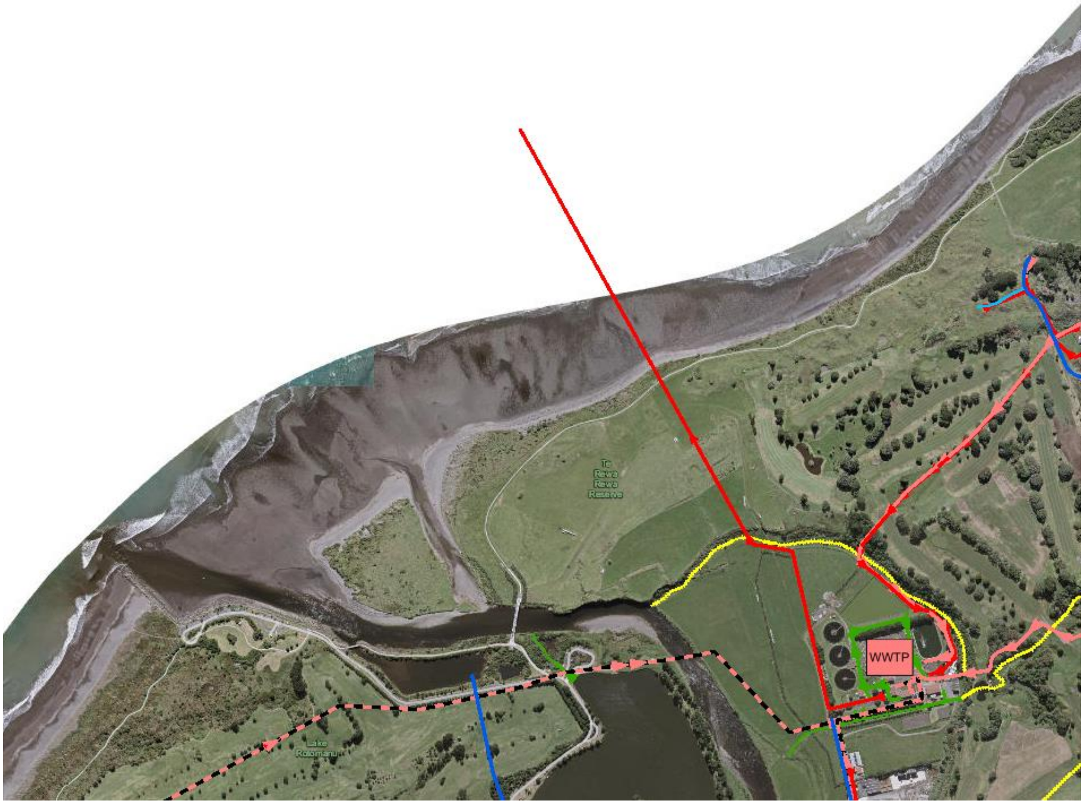

Figure A-2: Location of outfall for New Plymouth Wastewater Treatment Plant with respect to the WWTP and the Waiwhakaiho River. Figure supplied by NPDC.

Wastewater discharge characteristics:

Monthly summary statistics for total outflow from the disinfection clarifiers are shown in Table A-1 for data supplied by NPDC for 2018 – 2022.

Table A-1: Monthly statistics for outflow rate (m^3/d) for NPWWTP. Data combined from 2018-2022.

Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	124	113	124	120	124	120	124	133	150	155	150	154
Min	16379	14844	15079	15128	15859	18751	21163	15179	18565	16987	16641	17548
Max	27499	44377	32692	40345	37490	41332	43846	59530	32827	33358	55594	58489
Mean	20146	21363	19303	20924	23261	26746	28915	28603	24282	23873	23531	26837
5%ile	16929	16924	16190	16107	17369	21154	23547	20571	20147	19439	19160	18562
25%ile	18374	17941	17687	17901	20093	23148	26107	24732	22098	21489	20652	20704
Median	19464	19175	18753	19616	23197	25616	27898	26807	24127	23675	21750	24275
75%ile	22052	21446	20167	23052	25390	29298	30797	30149	25755	25847	24164	28599
95%ile	24454	35071	24272	30069	30200	35890	37969	47175	29615	29946	32069	47459

Annual summary statistics for total outflow from the disinfection clarifiers are shown in Table A-2 for data supplied by NPDC.

Table A-2: Annual statistics for NPWWTP outflows (m³/d). Data not available before 23/8/2018 due to prepopulation of data worksheet with error value.

Parameter	2018	2019	2020	2021	2022
Sample size	131	365	366	365	364
Min (m^3/d)	16987	16251	14844	15723	15859
Max (m^3/d)	32020	40345	58489	57177	59530
Mean (m^3/d)	21499	23198	23297	24492	26250
5%ile	18568	17809	16473	17507	17685
25%ile	20057	19638	18281	21749	20585
50%ile (median)	21001	22418	21831	24166	25163
75%ile	21946	25960	25490	26214	29865
95%ile	26806	31945	36368	31658	38924

Deseasonalised trend analysis for outflows m^3/d was carried out using TimeTrends. Seasonal trend was removed by subtracting seasonal variation derived by fitting a generalised additive model (GAM with 7 degrees of freedom) to seasonal data for the outflows m^3/d. The slope of the positive trend line fitted to deseasonalised data is 3.33 m^3/d (1216 m^3/yr or 5.05% per year).

t,df	12.3107,1589
H_0: no slope	Reject, P = 0.0000

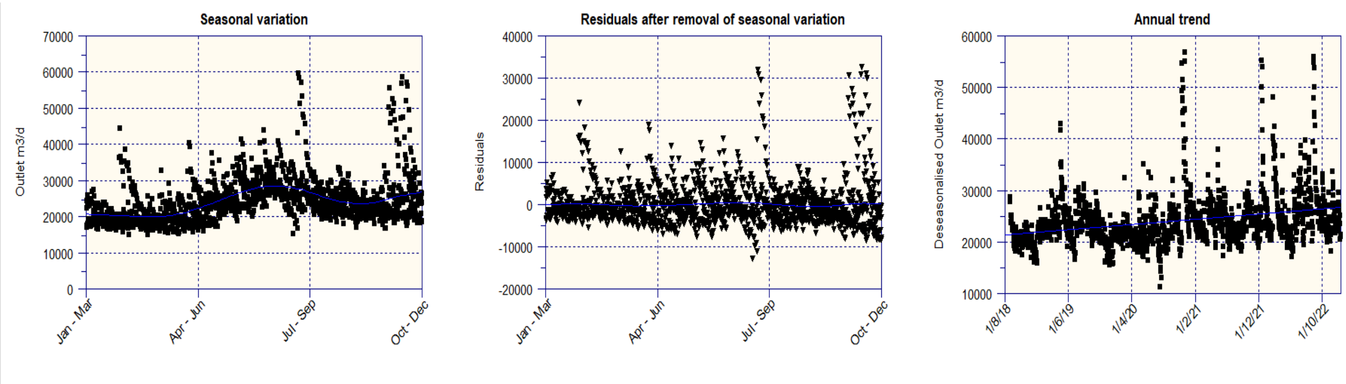

Figure A-3: Seasonal variation and deseasonalised trend in outflows m³/d from NPWWTP. Data from 2018-2022.

Wastewater microbial characteristics: Faecal indicator bacteria

Table A-3: Annual statistics for faecal coliform concentrations (#/100 mL) in disinfected treated wastewater for NPWWTP. Uncensored data. Limited data available for 2022.

Parameter	2017	2018	2019	2020	2021	2022
Sample size	146	146	140	148	144	9
Min	1	1	1	1	1	1
Max	45	67	40	75	84	6
Mean	7.36	6.01	4.53	6.18	5.53	2.89
5%ile	1	1	1	1	1	1
25%ile	2	2	1	2	1	1
50%ile (median)	4	3	3	4	2	1
75%ile	10	6	6	7	6	5.25
95%ile	20	18.4	15	19	20	-

Exploration of effluent monitoring data for faecal coliform concentrations for the period Aug 2018 to Jan 2022 for which outflow data is available, does not appear to show any evidence for a relationship between faecal coliform concentration in the outflow and flow rates (Figure A-4). Data is shown including censored values (typically <1 FC/100 mL) for which half the censored value (e.g., 0.5 FC/100 mL) is plotted. Total number of FC datapoints is 783 of which 12% are censored (“<” values).

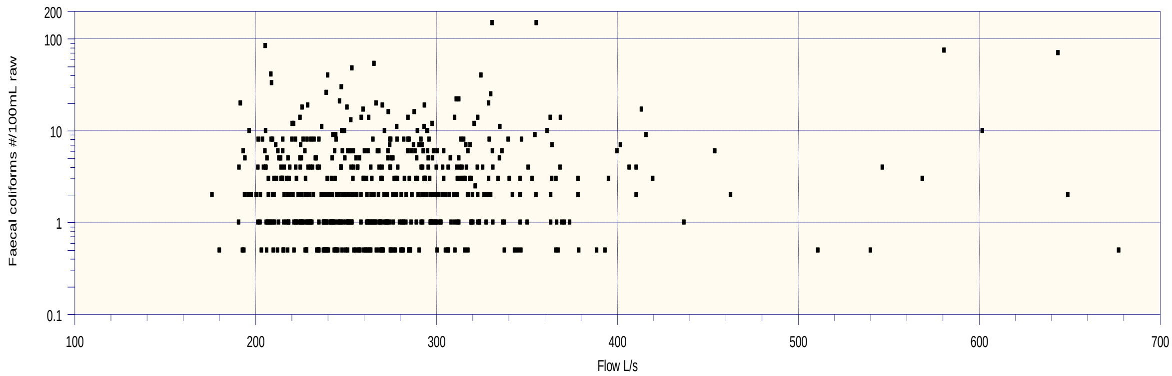

Figure A-4: Relationship of faecal coliform concentration (#/100 mL) in the effluent with outflow rates (L/s).

Wastewater microbial characteristics: norovirus

Data sets for norovirus concentrations in wastewaters contained a large proportion of censored data, particularly for effluent norovirus concentrations. A summary of the dataset for influent, clarifier effluent, and treated effluent is shown in Table A-4. A timeseries of available data is also shown in Figure A-5.

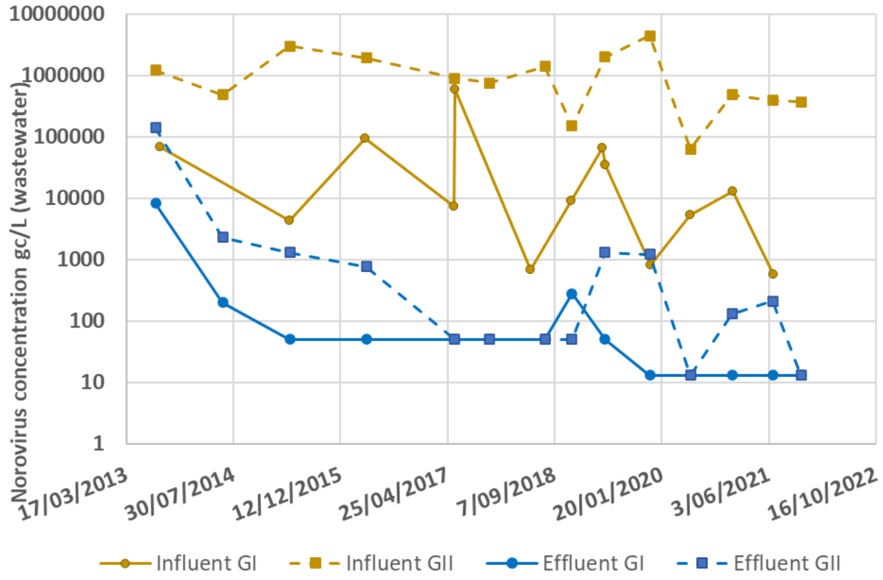

Figure A-5: Timeseries of norovirus concentration in influent and effluent wastewaters for NPWWTP shown for genogroup GI and GII. Censored data included. Note log_{10}-scale on y axis.

There is some evidence for seasonal variation in norovirus concentration in wastewaters with typically higher genome copies /L during autumn months (Mar – Apr). Other studies have reported greater norovirus concentrations in wastewater in the colder winter months (e.g. (Nordgren et al. 2009).

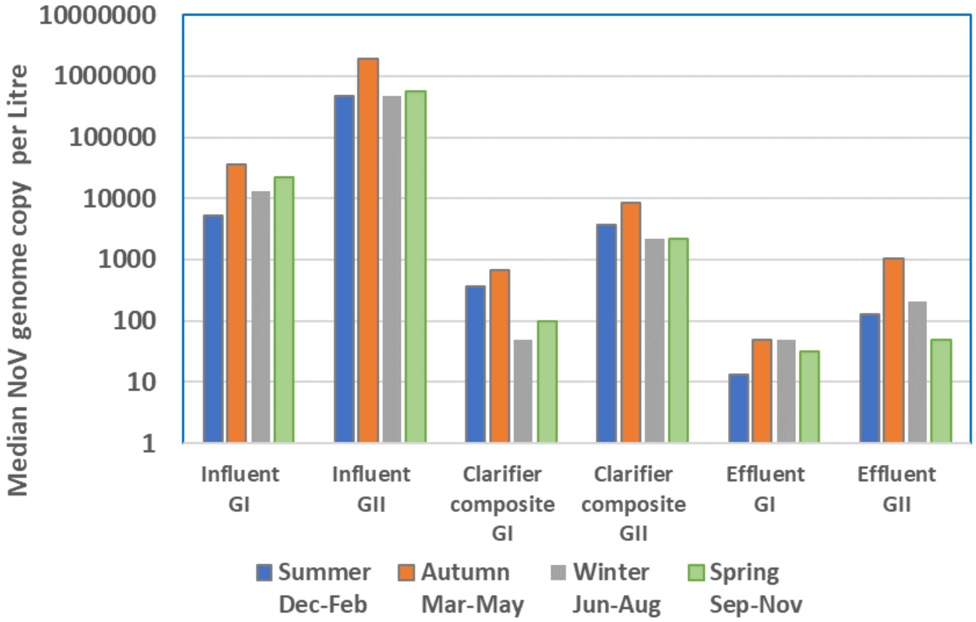

Figure A-6: Seasonal variation in median norovirus concentration in wastewaters from NPWWTP. All data used, summer (n=1) and values 50 or less are censored values (i.e. "<" values). Note log_{10}-scale on y axis.

Table A-4: Summary of norovirus datasets for influent, clarified effluent and final treated effluent for NPWWTP.

	Influent norovirus GI	Influent norovirus GII	Clarifier effluent norovirus GI	Clarifier effluent norovirus GII	Effluent norovirus GI	Effluent norovirus GII
Sampling dates	31/7/2013 – 1/11/2021		7/11/2017 – 1/1/2021		31/7/2013 – 1/11/2021	
No. of sample occasions	14		8		14	
No. uncensored values	14	14	5	7	4	8
No. censored values	0	0	3	1	10	6
% censored values	0	0	37.5	12.5	71.4	42.9
Uncensored values:						
Min gc/L	$5.7x10^2$	$6.3 x10^4$	$7.0x 10^1$	$1.9 x10^3$	$5.0x10^1$	$1.3x10^2$
Max gc/L	$6.0x10^5$	$4.4x10^6$	$5.3x10^3$	$8.6x10^3$	$8.2x10^3$	$1.4x10^5$
Median gc/L	$1.1x10^4$	$8.2x10^5$	$3.6x10^2$	$3.7x10^3$	$2.4x10^2$	$1.3x10^3$
Censored values:						
Min gc/L			<13	<50	<1	<13
Max gc/L			<50		<50	<50
Median gc/L			<50		<50	<50

<13 gc/L = limit of detection; <50 gc/L = limit of quantitation.

Table A-5: Removal of norovirus during wastewater treatment at NPWWTP. Log_{10} reduction values (LRV) based on censored data only.

	Secondary (pre disinfection) Norovirus GI	Secondary (pre disinfection) Norovirus GII	Secondary to tertiary treatment Norovirus GI	Secondary to tertiary treatment Norovirus GII	Final treated effluent (post disinfection) Norovirus GI	Final treated effluent (post disinfection) Norovirus GII
LRV (Log_{10}) for GI and GII individually:						
Min	0.76	1.73	0.73	0.26	1.51	2.32
Max	2.70	3.30	2.03	2.72	3.12	3.57
Average	1.73	2.40	1.24	1.41	2.38	3.24
LRV (Log_{10}) for combined norovirus (GI and GII data):						
Min		0.76		0.26		1.51
Max		3.30		2.72		3.57
Average		2.12		1.34		2.98

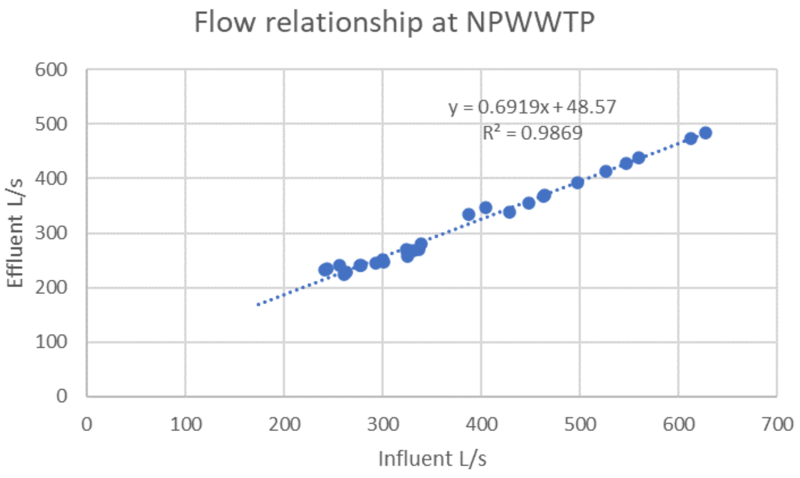

Figure A-7: Relationship between influent and effluent flow at NPWWTP used to estimate missing effluent flow rates for norovirus sampling 31/7/2013-23/7/2018.

The relationship between flows and norovirus genome concentrations is shown in Figure A-8. Censored data for effluent have been included as equal to the value of the censored data (i.e., <13 gc/L is taken as 13 gc/L). There may be a modest relationship between norovirus concentration and flow as evidenced by lower influent concentrations of GI and GII during increased flows, possibly attributed to dilution from the greater flows if associated with wet weather. A comparable pattern is observed in effluent concentrations.

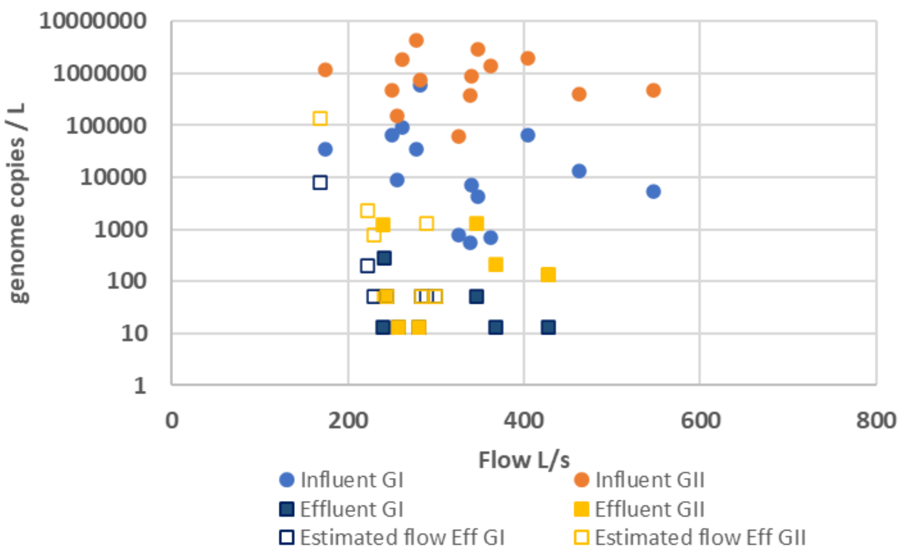

Figure A-8: Relationship between norovirus GI and GII genome concentrations and flows for influent and effluent at NPWWTP. Censored data included. Note log_{10}-scale on y axis.

Censured and uncensured data for log_{10} reduction values (LRV) for norovirus genogroups GI and GII are shown in Figure A-9 in relation to inflows (left) and outflows (right). There is little evidence to suggest that norovirus removal is reduced during periods of high flows within the range recorded here (Figure A-9).

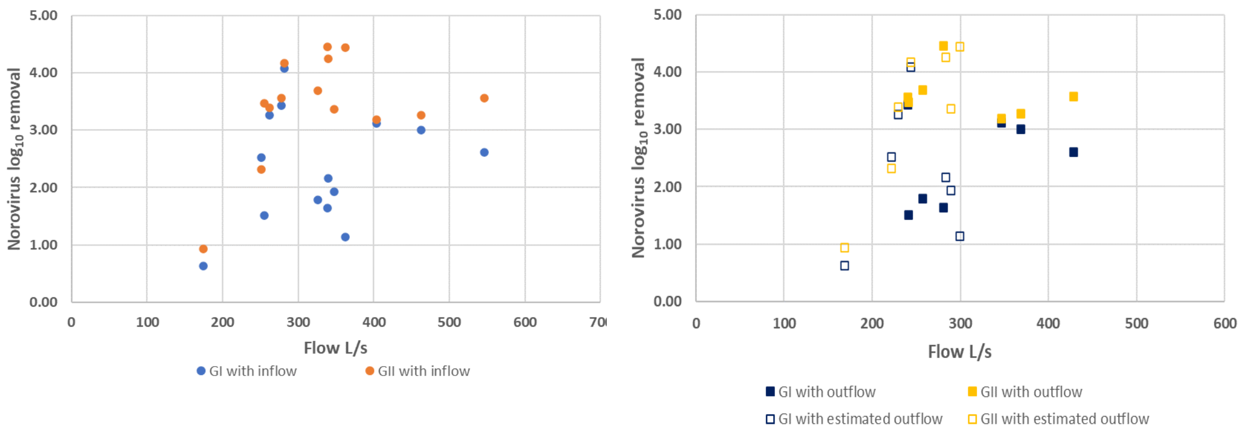

Figure A-9: Relationship of norovirus removal with inflow and outflow rates at NPWWTP. Data (2013-2021).

Appendix B Norovirus in Shellfish

Shellfish sampling sites for norovirus analysis are shown in Figure B-1. Mussels were collected on 16 sampling occasions from the Bell Block and Waiwhakaiho Reef sites between October 2012 to July 2022 as part of a water quality investigation into the potential impact of treated wastewater discharged from the New Plymouth Wastewater Treatment Plant. Mussels were also sampled from Oakura (as a control site) on three sampling occasions. On one occasion, mussels were also analysed from East End Beach and Kaweroa Reef. The closest stream or discharge to the shellfish sampling sites were the NPWWTP and the Waitaha Stream for Waiwhakaiho Reef and Bell Block respectively.

Shellfish were sampled pre and post upgrade (in 2013) and mainly during normal WWTP operation; on one occasion (August 2013) shellfish were sampled during bypass flow operation. Mussel flesh was analysed for norovirus (GI and GII genogroups) by ESR. The flesh from around 20 green lipped mussels was composited and 5g of tissue was typically used for testing. The limit of quantification (LOQ) was 80 genome copies per gram flesh.

A smaller shellfish monitoring campaign was also carried out for an investigation into the impact from the Waitara WWTP with mussel sampling sites at Orapa reef and Airedale Reef (refer to Figure B-2 for site location), and Waiongana River mouth.

Results from shellfish sampling are shown in Table B-1 for sites associated with the New Plymouth WWTP and in Table B-2 for sites associated with Waitara WWTP.

Figure B-1: Sampling sites for analysis of norovirus in mussel flesh for New Plymouth WWTP risk assessment. Oakura (control) site not shown; approximately 20km SW of outfall.

Figure B-2: Shellfish sampling sites for Waitara WWTP. Supplied by Kate Giles (NCDC).

Norovirus results reported as "low" were positive results but at a density below the level that could be quantified by the ESR laboratory i.e., less than 80 genome copies per gram flesh.

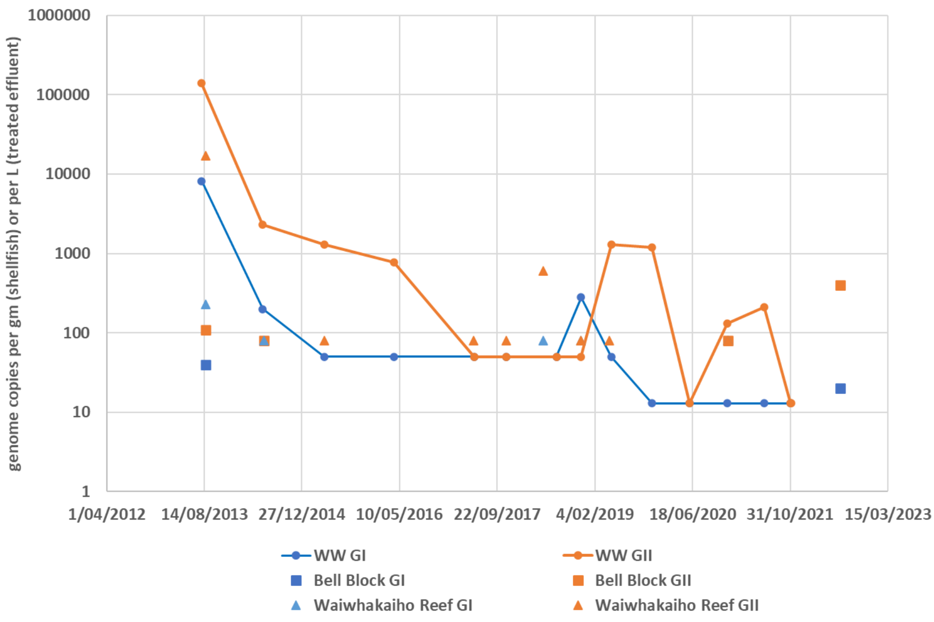

Figure B-3: Timeseries concentration of norovirus GI and GII in shellfish (mussels) and effluent wastewater. Note $\log_{10}$-scale on y-axis.

Table B-1: Shellfish testing for norovirus (genogroups GI and GII; New Plymouth WWTP. Green lipped mussel analysis 2012 - 2022 (data supplied by NPDC[17]).

Date	NP WWTP flow	NPWWTP	Bell Block GI	Bell Block GII	Waiwhakaiho GI	Waiwhakaiho GII	East End Beach GI	East End Beach GII	Kaweroa Reef GI	Kaweroa Reef GII	Oakura GI	Oakura GII
5/10/2012	normal	pre-upgrade	Negative	79	Negative	Negative					Negative	Negative
20/08/2013	bypass	post upgrade	40	110	230	17000					Negative	40
15/06/2014	normal	post upgrade	Negative	<80	<80	Negative	Negative	<80	Negative	Negative		
20/04/2015	normal	post upgrade	Negative	Negative	Negative	<80					Negative	Negative
6/04/2016	normal	post upgrade	Negative	Negative	Negative	Negative						
25/05/2017	normal	post upgrade	Negative	Negative	Negative	<80						
7/11/2017	normal	post upgrade	N/A[b]	N/A[b]	Negative	<80						
16/05/2018	normal	post upgrade	Negative	Negative	<80	600						
25/11/2018	normal	post upgrade	Negative	Negative	<80	<80						
18/04/2019	normal	post upgrade	Negative	Negative	Negative	<80						
28/11/2019	normal	post upgrade	Negative	Negative	Negative	Negative						
3/06/2020	normal	post upgrade	Negative	Negative	Negative	Negative						
15/12/2020	normal	post upgrade	Negative	<80	<80	<80						

[17] Concentration data supplied by Kate Giles, Land and Water Scientist, TRC, pers comm

Date	NP WWTP flow	NPWWTP	Bell Block GI	Bell Block GII	Waiwhakaiho GI	Waiwhakaiho GII	East End Beach GI	East End Beach GII	Kaweroa Reef GI	Kaweroa Reef GII	Oakura GI	Oakura GII
23/06/2021	normal	post upgrade	Negative	Negative	Negative	Negative						
4/11/2021	normal	post upgrade	Negative	Negative	Negative	Negative						
14/07/2022	normal	post upgrade	20	400	Negative	Negative						
Normal flow[a]												
% sampling occasions +ve			7.1%	14.3%	26.7%	46.7%						
(N+ve/total sampling occasions			(1/14)	(2/14)	(4/15)	(7/15)						

a: bypass flow conditions not included; b; no mussels found for sampling. Limit of quantitation is 80 genome copies/gm (gut). Yellow= low contamination; orange = moderate contamination, red= high contamination

Table B-2: Shellfish testing for norovirus (genogroups GI and GII); Waitara WWTP. Green lipped mussel analysis 2010 - 2020.. Data supplied by NPDC.

Date	Waitara WWTP operation	Orapa Reef GI	Orapa Reef GII	Airedale Reef GI	Airedale Reef GII	Waiongana River mouth GI	Waiongana River mouth GII
10/08/2010	Normal: Discharging	Low	Moderate	Negative	Low		
24/08/2010	Normal: Discharging	Negative	Low	Negative	Low		
6/12/2010	Normal: Discharging	Negative	Negative	Negative	Low		
20/04/2015	Ceased Discharging	Negative	Negative	Negative	Negative		
8/05/2016	Following unauthorised sewage discharges	Negative	Negative	Negative	Negative	Negative	Negative
28/11/2019	Taken as precaution because NPWWTP bioreactor shut down	Negative	Negative				
15/12/2020		Low	Low	Negative	Low		
Normal flow[a]							
% sampling occasions +ve (N+ve/total sampling occasions		28.6% (2/7)	42.9% (3/7)	0% (0/6)	66.7% (4/6)	0% (0/1)	)% (0/1)

a: bypass flow conditions not included; Low=≤ 80 genome copies/g, Moderate =80-320 gc/g

Appendix C Recreational Water quality

QMRA Recreational risk sites

The location of sites used in previous QMRAs for human health risk assessment for recreational activities are shown in Table C-1 and Figure C-1 from McBride (2012).

Microbiological water quality at shoreline sites

A summary of microbiological water quality for shoreline monitoring sites and recreational water quality sites are shown in Table C-2. Hazen 95th percentiles were calculated using the Hazen Percentile Calculator (McBride, NIWA, Hamilton, 2002); censored "less than" data were replaced by half their detection limit.

Table C-1: Location of sites used for QMRA, shoreline water quality monitoring, Recreational Water Quality Monitoring and shellfish monitoring.

Site	Longitude	Latitude	TRC code	Site
			SEA901030	Airedale Reef
	174.2308	-38.9873	SEA901033	Waitara East Beach
	174.2233	-38.9884	SEA901037	Waitara West Beach
			SEA901040	Orapa Reef
E12	174.1981	-38.9874		
E11	174.1858	-38.992		
E10	174.1742	-38.9969		
E9	174.1585	-39.0133	SEA902001	Bell Block
E8	174.1471	-39.0184		
E7	174.1457	-39.0142		
E6	174.1411	-39.0166		
E5	174.1374	-39.0156		
E4	174.1326	-39.0193		
E3	174.1271	-39.0254	SEA902008	1.5km NE (aka Mangati)
E2	174.1226	-39.0281		
E1	174.1194	-39.0313	SEA902010	300m NE outfall
Inshore	174.1134	-39.0322		
W1	174.1046	-39.0338		
W2	174.106	-39.0347	approx SEA902015	500m SW (West) Waiwhakaiho Reef
			WKH000950	Waiwhakaiho River adjacent to Lake Rotomanu
W3	174.1028	-39.0374		
W4	174.101	-39.0394		
W5	174.0982	-39.0427		

Site	Longitude	Latitude	TRC code	Site
W6	174.096	-39.0448	SEA902025	Fitzroy Beach (opp surf lifesaving club)
W7	174.0946	-39.046		
W8	174.0921	-39.0475	SEA902035	East End Beach
W9	174.0849	-39.049		
W10	174.0782	-39.0493		
W11	174.0752	-39.0544		
W12	174.0695	-39.0547		
W13	174.0623	-39.053		
W14	174.058	-39.0549	SEA902055	Kaweroa Reef*
W15	174.0536	-39.056		
W16	174.0406	-39.0588	SEA902062	Ngamotu Beach
W17	174.0198	-39.061		
W18	174.018	-39.0673	SEA902070	Back Beach
			SEA903020	Oākura
			SEA903030	Oakura Beach opp. surf lifesaving club
			SEA903032	Oakura Beach campground

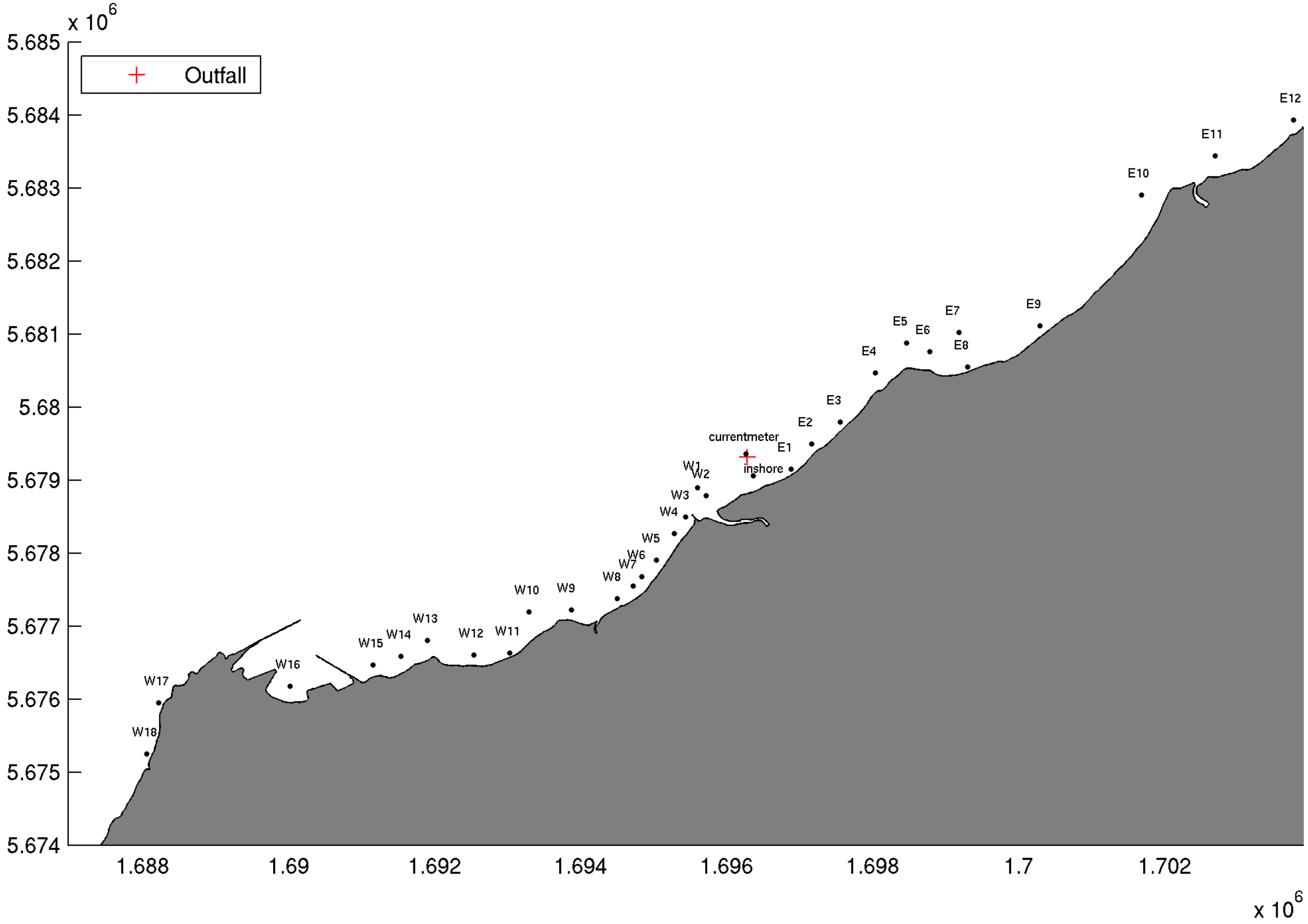

Figure C-1: New Plymouth coastline with sites used for QMRA prediction 1-E12). west of the outfall (W1-W18), and one inshore ("inshore"). Figure sourced from McBride 2012.

Table C-2: Summary statistics for recreational water quality. TRC site code (SEA9020XX) and 2023 QMRA codes (W, or E) shown.

Statistic	Back Beach (SEA902070) (W18)					Ngamotu Beach (SEA902062) (W16)					East End Beach (SEA902035) (W8)				
	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL
N of cases	26	26	61	33	94	52	52	100	34	134	52	52	100	33	133
Minimum	<1	<1	1	< 10	< 10	<1	<1	<1	< 10	<1	<1	<1	<1	< 10	<1
Maximum	700	750	12000	488	12000	380	400	3000	313	3000	140	140	820	573	820
N "<" values	1	1	0	6	6	12	12	11	15	26	9	8	16	17	33
Median	42	44	30	30	30	11	11.5	13	31	15	11	10	9	20	10
95%ile (Hazen)	620	710	488	481	421	179	179	190	257	133	68	78	130	206	144
Proportion sample>43 FC/100mL (n/N)		50% (13/26)					12% (6/52)					12% (6/52)			

Statistic	Fitzroy Beach SEA902025) (W6)					Waiwhakaiho 500m SW of outfall (SEA902015) (~W2)					Waiwhakaiho River @ Lake Rotomanu (WKH00950)				
	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL
N of cases	52	52	100	33	133	25	25	25		25	26	26	26		26
Minimum	<1	<1	<1	< 10	<1	<2	<2	<1		<1	46	69	28		28
Maximum	89	99	1200	108	1200	270	270	1200		1200	7400	8000	7500		7500
N "<" values	17	17	23	25	48	1	1	1		1	0	0	0		0
Median	5	5	4	36	4	30.5	33.5	40.5		40.5	865	950	690		690
95%ile (Hazen)	38	39	70	101	77	218	218	960		960	3640	4160	4460		4460
Proportion sample>43 FC/100mL (n/N)		4% (2/52)					36% (9/25)					NA			

Statistic	300m NE outfall (SEA9020105) (E1)					1.5 km NE Outfall/ Mangati (SEA902008) (E3)					Bell Block (SEA902001) (E9)				
	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL	EC CFU/100mL	FC CFU/100mL	Ent CFU/100mL	Ent MPN/100mL	Ent[a] #/100mL
N of cases	25	25	50		50	26	26	51		51	27	27	39	33	72
Minimum	<1	<1	<1		<1	<1	<1	<1		<1	1	1	<1	< 10	<1
Maximum	88	99	1900		1900	24	29	110		110	150	150	440	399	440
N "<" values	4	4	4		4	13	13	23		23	0	0	2	7	9
Median	11	11	10		10	5	5	3		3	5	7	15	52	21
95%ile (Hazen)	52	55	350		350	14	15	82		82	88	91	90	242	231
Proportion sample>43 FC/100mL (n/N)		4% (1/25)					0 (0/26)					11% (3/27)			

a: all enterococci data combined from both methods if available- results from CFU and MPN were considered equivalent.

Table C-3: Microbiological Recreational water quality data available for bathing seasons for each site and included in analysis.

Bathing season	Back Beach	Ngamotu	East End	Fitzroy	Waiwhakaiho 500 m SW outfall	Waiwhakaiho River	300 m NE outfall	1.5 km NE Outfall	Bell Block	Waitara West	Waitara East
2013-2014	Y	Y	Y	Y	y	y	y	y	y	Y	Y
2014-2015		Y	Y	Y						Y	Y
2016-2017	Y	Y	Y	Y	y	y	y	y	y	Y	Y
2018-2019	Y	Y	Y	Y			y	y		Y	Y
2019-2020									y		
2020-2021	Y	Y	Y	Y			y	y		Y	Y
2021-2022	Y	Y	Y	Y					y	Y	Y