Faecal contaminant load reductions for the protection of estuarine recreational values

Bay of Plenty Regional Council
Environmental Publication 2022/13

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ISSN: 1175-9372 (Print)
ISSN: 1179-9471 (Online)

Acknowledgements

Thank you to the Environmental Data Services team for collecting the samples and carrying out the field work that forms the basis of this report. Thanks also go out to everyone who reviewed or commented on this report, including (but not limited to): Rochelle Carter, Nicki Green, Paul Scholes, and Rob Donald. Thanks in particular to Ned Norton for a constructive and extremely useful external review.

Publishing Information

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Reviewer	Details	Date
Rochelle Carter (Principal Advisor, Science - BOPRC)	*Internal review for content*	*7 June 2022*
Nicola Green (Principal Advisor, Policy and Planning – BOPRC)	*Internal review for content*	*20 May 2022*
Paul Scholes (Senior Environmental Scientist – BOPRC)	*Internal review for content*	*15 June 2022*
Ned Norton (Subject Expert - Land Water People)	*External review*	*30 August 2022*

Recommended citation

Dare, J., Cotterill, V. (2022). Faecal contaminant load reductions for the protection of estuarine recreational values. Bay of Plenty Regional Council Environmental Publication 2022/13.

Executive summary

Bay of Plenty Regional Council (BOPRC) is working towards incorporation of the National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2020) via an internal programme entitled the 'Essential Freshwater Policy Programme' (EFPP). The EFPP outlines numerous information reporting tasks for relevant council teams, which will be used to re-develop the Regional Natural Resources Plan (Bay of Plenty Regional Natural Resources Plan, 2008). The deadline for delivery of this work is set at June 2024, with all scientific reporting tasks due by the end of 2022. From a science perspective, these deadlines are not ideal as many EFPP tasks do not align perfectly with existing routine monitoring programmes leaving knowledge gaps in some areas. However, the NPS-FM sets out a requirement to use the 'best information available at the time' to ensure that deadlines are met, meaning that BOPRC is required to make the best use of existing information even if it is not specifically designed to answer a given task.

This report attempts to address Task 4 (c) in the Essential Freshwater workstream, part of the EFPP. The objective of this task is to estimate faecal contaminant load limits from freshwater body inputs to Coastal Receiving Environments (CREs) that would support CRE objectives. Desired information to achieve this task includes: an understanding of the state of sites where CRE objectives are measured, identification of freshwater bodies that influence CRE objective sites, and a thorough understanding of hydrodynamic and transport processes that link identified freshwater sources with the CRE objective site, i.e., a catchment load model coupled with a hydrodynamic model for each estuary. Unfortunately, these models are costly, take a long time to develop, and require targeted data beyond that of routine monitoring programmes. For this reason, BOPRC has decided to collate and analyse existing information from various routine or ad-hoc monitoring programmes, providing as much information as possible to help achieve Task 4 (c), while acknowledging and reporting knowledge gaps and uncertainty where they exist.

Routine recreational bathing and shellfish harvesting monitoring data was used to represent current state and to compare with options for CRE objectives. Attribute tables based on the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MWQG) were developed and used to establish options for the CRE objectives, including a Proposed Minimum Acceptable State (PMAS) as well as higher state options (e.g., A, B or C band state) for each attribute. These attribute tables were similar to those established by some other councils, The attribute tables were applied to existing datasets as a preliminary analysis of whether current water quality met the PMAS and/or higher state bands. Results showed that all estuarine and coastal recreational bathing sites were in better condition than the Proposed Minimum Acceptable State (PMAS), however, nine of the 11 monitored shellfish harvesting sites breached at least one of the dual proposed PMAS thresholds for shellfish harvesting. Breaches occurred for sites located within Tauranga Harbour, Maketū Estuary, Waihī Estuary, Ōhiwa Harbour, and Waiōtahe Estuary.

Each of the nine failing shellfish harvesting sites were investigated on a site-by-site basis. All available, relevant, information was collated and analysed to help with the Task 4 (c) objective. For all sites, this consisted of at least: i) identifying the site-specific concentration reduction required to meet PMAS thresholds, ii) identification of freshwater inputs that were likely to contribute contamination to the site, iii) a load duration curve analysis for inflows with routine monitoring data available, and iv) estimation of the catchment faecal contaminant load reduction required to meet in-stream (freshwater) objectives (Table 9 or Table 22 of Appendix 2 of the NPS-FM). Load reductions calculated through this process are summarised in Table ExSum 1. It is assumed that improving contributing inflows to a swimmable state will benefit conditions at the designated shellfish harvesting site although it is unknown by how much. Therefore, load reduction percentages are shown for contributing inflows and the 'benefit' column shows whether the calculated reduction will meet swimming condition thresholds within the inflow or can be linked to suitable harvesting conditions at the estuarine shellfish site.

Additional information was considered where available to the specific receiving environment. This included: i) the use of the existing Tauranga Harbour DELWAQ hydrodynamic model (Bryan & Stewart, 2022) to simulate inert particle transport throughout the harbour, providing a possible relative contribution of freshwater inflow derived contaminants at each CRE objective site; ii) analysis of a small scale investigation in Ōhiwa Harbour to determine the extent of contamination along the shoreline adjacent to the shellfish harvesting site; and iii) application of a simple dilution model for Waiōtahe Estuary to calculate the load reduction required to meet shellfish harvesting PMAS thresholds within the estuary. Furthermore, Maketū and Waihī Estuary shellfish harvesting sites had previously been comprehensively modelled by DHI Water & Environment Ltd, with results including estimates of catchment faecal bacteria load reductions needed to achieve the dual proposed PMAS thresholds being presented to BOPRC in 2021. These results were summarised for both estuaries in this report, but no additional analyses or investigation was carried out.

Finally, to help address Task 4 (c) using the best available information in the timeframe, but with transparency about uncertainties, this report is structured by presenting knowledge for each site under the sub-headings: 'Knowledge to Date', 'Knowledge Gaps', and 'Recommended Future Work'. The intention was to ensure absolute transparency to the reader, as most analyses are based on a 'patchwork' of datasets from numerous routine and ad-hoc monitoring programmes, rather than being specifically designed to answer Task 4 (c) objectives. The most common uncertainties across all sites included the lack of a hydrodynamic model with a coupled faecal transport module to translate loads from each inflow to estuarine concentrations at shellfish harvesting sites, and a lack of data from other within-estuary sources. Regardless of these caveats, this work provides BOPRC's best attempt at understanding the current freshwater catchment influence over faecal contamination within estuaries and outlines a direction to improve this understanding into the future.

Table ExSum 1 A summary of load reductions calculated through the site investigation process. The full table is available in Table 27.

Shellfish Harvesting Site	Inflow	Benefit	Max Load Reduction
Waihī Beach at Three Mile Creek	Three Mile Creek	N/A	N/A
Tauranga Harbour at Anzac Bay	Tuapiro Stream	Instream swimming	1%
	Waiau River	Instream swimming	59%
Tauranga Harbour at Bowentown Boat Ramp	Tuapiro Stream	Instream swimming	1%
	Waiau River	Instream swimming	59%
Tauranga Harbour at Te Puna Waitui Reserve	Te Puna Stream	Instream swimming	0%
Tauranga Harbour at Tilby Point	Wairoa River	Instream swimming	65%
Waihī Estuary at Main Channel	All	Shellfish harvesting	51%
Maketū at Surf Club	All	Shellfish harvesting	39%
Ōhiwa Harbour at Reserve	Nukuhou River	Instream swimming	69%
Waiōtahe at Estuary	Waiōtahe River	Instream swimming	54%
	Waiōtahe River	Shellfish harvesting	93%

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Part 1:
Introduction

Bay of Plenty Regional Council (BOPRC) is currently working to implement the National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2020) through an internal work programme called the 'Essential Freshwater Policy Programme' (EFPP). The EFPP comprises numerous analytical and data collation tasks that are split into workstreams and delegated to the most relevant expert teams throughout the council. Each team is required to deliver delegated tasks within a tight timeframe so that information can be used to update the Regional Natural Resources Plan (Bay of Plenty Regional Council, 2017) to give effect to the NPS-FM, which will be publicly notified shortly after the EFPP due date of June 2024. The NPS-FM states that the 'best information available at the time' should be used to achieve specific tasks, to ensure that deadlines are met.

A fundamental part of the NPS-FM process is an assessment of current ecosystem state. This is achieved through comparison of site specific data from existing monitoring programmes, to water quality and ecological attribute tables defined within Appendix 2A and 2B of the NPS-FM, as well as regional attributes defined by BOPRC (refer to Carter et al., 2017). Each attribute table provides band categories based on attribute statistics which are used to grade the state of a freshwater site. Regional councils have the responsibility of maintaining or improving the state of water quality attributes at each site by setting target attribute states (TAS). TAS may relate to community aspirations, be driven by compulsory improvement beyond national bottom line (NBL) thresholds outlined in the NPS-FM, or be set according to 'baseline state', i.e., the state of each site on (or near to) September 2017.

This process is applicable to all freshwater bodies within the region; however, the NPS-FM does not specifically address estuarine or coastal environments. Instead, section 1.5(1) states:

This National Policy Statement applies to all freshwater (including groundwater) and, to the extent they are affected by freshwater, to receiving environments (which may include estuaries and the wider coastal marine area).

This means that there are no prescribed attribute tables for estuarine or coastal environments at the time of writing, leaving regional councils the responsibility of assessing the impact of freshwater inputs upon these areas by deriving their own attribute criteria.

Purpose of This Report

Most scientific tasks in the Essential Freshwater workstream of the EFPP involve the provision of expert advice, assessment of representativeness of existing monitoring programmes, or calculation of ecosystem state. These tasks are relatively easily completed using data from existing monitoring programmes. However, some tasks in the EFPP are not covered by the objectives of any existing routine monitoring, meaning that data from multiple programmes needs to be drawn together in the best attempt to satisfy task requirements. In these cases, data is often not entirely 'fit for purpose' and there are likely to be knowledge gaps that fall between each of the monitoring programmes used.

Task 4 (c) is a good example of an EFPP task that falls between multiple monitoring programmes. The main objective of this task is defined as:

To estimate (faecal) contaminant load limits from freshwater body inputs to coastal receiving environments that would support Coastal Receiving Environment (CRE) objectives.

This task requires an understanding of the current state of coastal and estuarine receiving environments relative to CRE objectives, the source of freshwater inputs that impact on attainment of these objectives, and an understanding of faecal contaminant transport and survival processes that lead to the conditions observed at the CRE objective sites (i.e., human health sites monitored as part of the Recreational Bathing Programme).

Ideally BOPRC would address this by collecting relevant data that would allow for development of a coupled catchment and estuarine hydrodynamic model. This would allow contamination from freshwater, estuarine, and oceanic inputs to be linked to concentrations (reported as state) at designated bathing and shellfish harvesting sites, through contaminant transport and decay processes within the estuary. However, bespoke catchment and hydrodynamic models are expensive, ‘data hungry’, and specific to each estuary (or sub-estuary) (Plew et al., 2015). Given current looming deadlines, BOPRC does not have the time or financial resources to establish models for all CRE objective sites, meaning that Task 4 (c) analyses are limited to data collected through the Recreational Bathing Programme, National Environmental Reporting and Monitoring Network, Focus Catchment Programme, or any other ad-hoc investigation of relevance. Most samples in these programmes are collected on a monthly basis, aside from Recreational Bathing (and shellfish harvesting) samples which are collected weekly between October and April each year.

This report collates and analyses the best available current-state information for estuarine and coastal recreational sites, as well as providing information on likely faecal contaminant load contributors (sources) for sites that breach CRE objectives. A best attempt has been made to provide an indication of the magnitude of faecal contaminant load reductions from freshwater environments that will help improve conditions at CRE objective sites, but in most cases a specific load limit is yet to be established. Sites used for this analysis are all from existing monitoring networks, i.e., no additional information has been collected at this stage, aside from a small investigation within Ōhiwa Harbour. This means that most, if not all, sites experience knowledge gaps that are unable to be filled using existing information. These gaps have been highlighted and presented alongside results to ensure transparency.

Part 2:
Methods

2.1 Proposed Attribute Tables

As there are currently no defined attribute tables or TAS for estuaries, expert knowledge was used to derive the most appropriate attribute tables, as well as a 'proposed minimum acceptable state' (PMAS) that is akin to the National Bottom Line (NBL) in the NPS-FM. Proposed attribute tables are based on existing attribute tables that are outlined in the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MWQG), using similar methodology to that derived by Environment Southland (Bartlett et al., 2020), while PMAS are based on thresholds that have been derived as minimum standards for human health in the MWQG. For the purpose of this report, PMAS have been adopted as the TAS for all sites, which in turn are assumed to meet CRE objectives. This means that any site that is worse than the PMAS progresses to the load-reduction stage of this analysis (Part 4). It is acknowledged that there are many caveats with this approach, for example, the PMAS represents the lowest (least conservative) possible TAS for a given site, and that higher community aspirations would be likely to result in greater faecal contaminant load reductions required and hence more conservative limits. It is also noted that these tables may change throughout the NPS-FM implementation process, however changes are unlikely to be dramatically different from the tables presented below.

2.2 Recreational contact in estuarine and marine waters

Suitability for recreational contact in brackish and saline waters is measured using enterococci as an indicator as per the MWQG (MfE, 2003). BOPRC monitors designated estuarine and coastal bathing sites weekly between October and April, with any exceedances of health guidelines being presented to the district health board (Toi Te Ora) who may choose to issue public health warnings (Dare, 2020).

The proposed attribute table for these environments has been derived from the Microbiological Assessment Category (MAC) for Marine Waters (Table D1 in the MWQG) (Table 1) and uses the 95th percentile value of enterococci results collected over a five-year period. The PMAS for this attribute is set at 500 CFU/100ml, as per the C/D threshold in table D1 of the MWQG.

Table 1 The attribute table used for estuarine and coastal recreational bathing sites. The proposed minimum state is used to define which sites require load reductions. This attribute is calculated over a five-year period from recreational bathing data which is collected weekly between October – April.

Value	Human health for recreation
Freshwater body type	Primary contact in estuaries and open coast
Attribute Group	Bay of Plenty Regional attribute
Attribute Name	Enterococci
Attribute Band	Numeric Attribute State
	95th percentile Enterococci (CFU/100ml)
A	≤40
B	>41 and ≤200

Value	Human health for recreation
C	>201 and ≤500
Proposed minimum acceptable state	500
D	>500

**Attribute is calculated over a five-year period from recreational bathing data.*

2.3 Shellfish harvesting in estuarine and marine waters

Bay of Plenty Regional Council monitors waterbodies over shellfish harvesting sites on a weekly basis during the summer recreational period (October-April). Samples are analysed for faecal coliforms as per the MWQG (MfE, 2003).

The proposed attribute table for shellfish harvesting is shown in Table 2. This table is based upon Box 3 in the MWQG which states that the median faecal coliform content of samples taken over a shellfish-gathering season shall not exceed a Most Probable Number (MPN) of 14/100 ml, and not more than 10% of samples should exceed an MPN of 43/100 ml. The percent exceedance attribute can be reworded as the 90th percentile value shall not exceed 43 CFU/100 ml. The one point of difference with the MWQG is that a time period of five years has been recommended to account for inter-annual variability, rather than a single harvesting season as stated in the MWQG.

Unlike other attribute tables, the shellfish harvesting table has no bands, consisting simply of a pass-fail grading, where the PMAS has been set at the pass-fail boundary. The worse of the two assessments (median and 90th percentile) is adopted to represent the overall state for this attribute, consistent with the approach to other attributes in the NPS-FM with more than one statistic or metric.

Table 2 The attribute table used for shellfish harvesting sites. The proposed minimum state is used to define which sites require load reductions.

Value	Human health for recreation	
Freshwater body type	Shellfish harvesting in estuaries and open coast	
Attribute Group	Bay of Plenty attribute	
Attribute Name	Faecal Coliforms	
Attribute Band	Numeric Attribute State	
	Median Faecal Coliforms (CFU/100ml)	% Exceedance of 43CFU/100ml Faecal Coliforms (CFU/100 ml)
Pass	≤14	≤10
Proposed minimum acceptable state	14	10
Fail	>14	>10

2.4 Preliminary Assessment of State

Bay of Plenty Regional Council monitors 15 estuarine recreational bathing, eight estuarine shellfish sites, 13 coastal recreational bathing, and 11 coastal shellfish harvesting sites using methodology outlined in the MWQG (MfE, 2003). These sites are likely to be impacted by freshwater inflows and therefore require an assessment of state to determine if current conditions meet TAS (PMAS) thresholds. If the current state of CRE objective sites exceeds PMAS thresholds, then a more detailed investigation into the source of contamination needs to be carried out, including calculation of load reductions required for CRE objectives to be met.

A preliminary assessment of state was carried out in Part 3 by assessing all data collected at estuarine and coastal recreational bathing and shellfish harvesting sites over the most recent five years, against the proposed recreational bathing and shellfish attribute tables (Table 1, Table 2). This analysis provided a list of sites that exceeded the PMAS for each proposed attribute, requiring progression to the site-specific investigation and load reduction section of this report (Part 4).

2.5 Site-Specific Investigations

The purpose of Part 4 of this report is to investigate sites that breach PMAS thresholds on a site-by-site basis and to provide information that may be helpful for policy development, or the prioritisation of on-ground action to understand where improvement is needed.

Whilst this report uses the best available information, it is acknowledged there are many information gaps which reduce the certainty of load reduction estimates. Therefore, the approach to this task has been to provide as much information as possible, where it exists, outline what is known, what is not known, and provide recommendations on how knowledge can be improved in the future. Information has been gathered and arranged into the following categories:

- **Site data and contaminant sources –** an overview of the site location and potential sources of contamination that may influence faecal indicator bacteria concentrations at the shellfish harvesting site.
- **Required concentration reduction –** a brief assessment using the best available information to determine the approximate concentration reduction required at each site.
- **Load reduction –** an analysis of any freshwater inflows identified in the contaminant sources section, where relevant freshwater attribute tables in the NPS-FM are used to determine load reductions.
- **Knowledge to date –** a simple summary of the information gathered to date, including new information obtained through this analysis.
- **Knowledge gaps –** a brief summary of identified knowledge gaps.
- **Recommended future work –** an expert opinion on how some of the knowledge gaps can be filled in the future.

2.6 Site data

Enterococci or faecal coliform data from estuarine or coastal bathing or shellfish harvesting sites were extracted from the BOPRC council water quality database (Aquarius) and truncated to a five-year period spanning 1 July 2016 to 1 July 2021. These data were used for the preliminary assessment and also site-specific investigations (if applicable).

Inflows in proximity to the PMAS breaching CRE objective sites were investigated to determine available data, and any relevant information was extracted accordingly. If possible, datasets were aligned to the five-year period (2016-2021) to provide inflow conditions that are consistent with results at CRE objective site. If no data were available for the 2016-2021 analysis period, any available historical information was used in accordance with using the best available information.

Flow data was obtained from continuous hydrological sites and summarised to mean hourly flow values. Some inflows lacked hydrological sites but contained numerous spot gauging measurements (e.g., National Environmental Reporting Monitoring Network (NERMN) water quality sites). These datasets were less preferable to continuous data records but were able to be summarised into broad flow and load distribution curves, which suits the purpose of this report using the best available information.

The Ōhiwa Harbour source investigation was carried out as a separate project over the period of six weeks (October-November 2021). This data was collated and analysed accordingly.

2.7 Contaminant sources

Coastal Receiving Environment objective sites were observed from GIS images and harbour channel morphology was used to identify major inflows that could impact each site. Additional possible sources were identified based on the location of the site relative to potential inputs, e.g., urban septic inputs, fringing agricultural inputs, background estuarine inputs (e.g., avian, or piscine contamination), or oceanic inputs.

Analysis for Tauranga Harbour CRE objective sites used the Tauranga Harbour DELWAQ hydrodynamic model (Bryan & Stewart, 2022) to determine contributing inflows for each site. This model was designed for nutrient transport but was able to be used to trace particle to explore how freshwater inflows are predicted to be transported around Tauranga Harbour. The model also allowed spatial locations (i.e., recreational sites) to be interrogated to estimate the relative contribution from inflows at each site. The particle tracer module of the DELWAQ hydrodynamic model was run specifically for this project and therefore results are not reported elsewhere.

2.8 Concentration reductions

Estimates of faecal contaminant reductions required at CRE objective sites to meet PMAS thresholds, were calculated using a cumulative distribution (Figure 1). The cumulative distribution enabled the current distribution to be depicted, while guideline statistics could be added to show where the distribution exceeded PMAS thresholds. Estimates of the percentage concentration reduction required were calculated by dividing the PMAS threshold value by the proposed attribute statistic calculated from the current dataset, and then subtracting that from 100. The current distribution (Reduction_0 in Figure 1) could be multiplied by the reduction and plotted as an additional line showing how the distribution would look if this reduction was achieved.

The major caveat with this approach is that the shape of a distribution was assumed to be consistent as reductions are made, which is unlikely to reflect reality. Notwithstanding this assumption, the method delivers an approximate estimate of the concentration reduction required to achieve the PMAS.

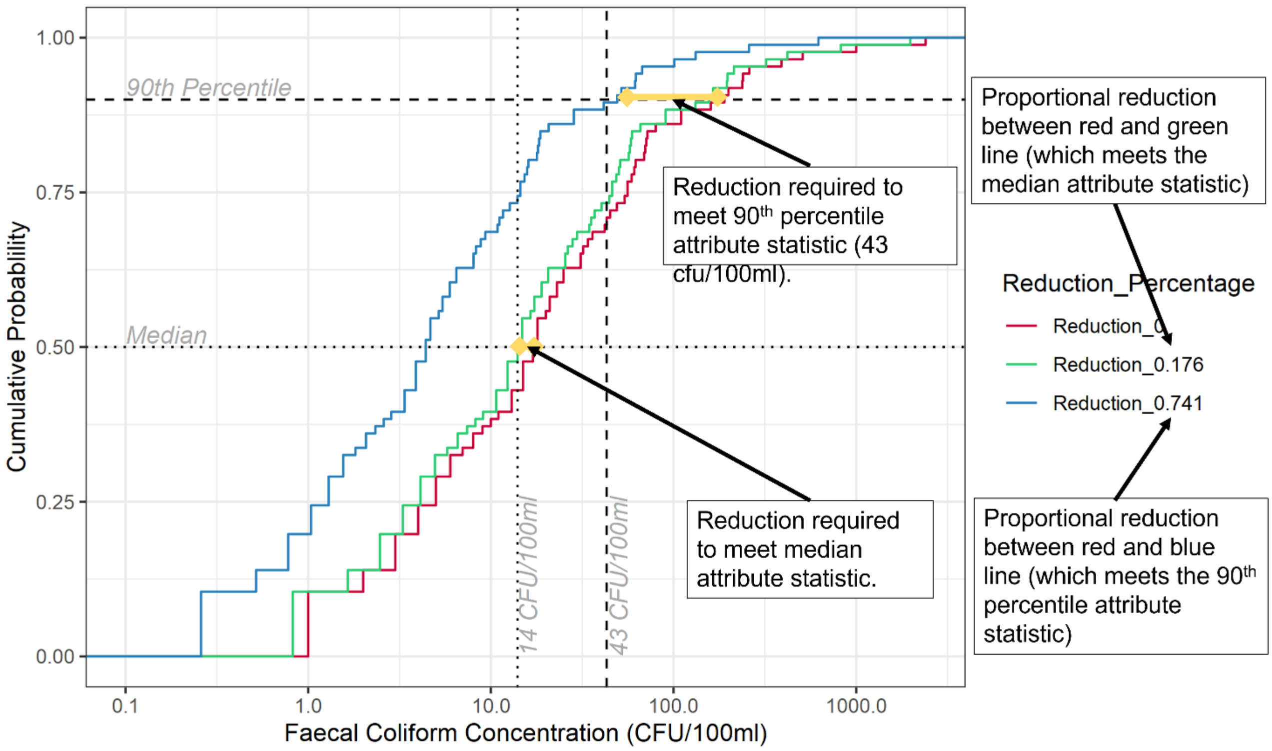

Figure 1 *An example of how cumulative distributions were used to calculate the proportional load reduction required to meet proposed attribute PMAS thresholds. This figure shows a hypothetical distribution of data from a shellfish bathing site. Concentration reductions required to meet PMAS thresholds are depicted as a yellow horizontal line between the red line (current distribution) and the blue (distribution that meets 90th percentile guideline) and green (distribution that meets median guideline) lines. In this example, a 74% reduction in concentration is required to ensure that the 90th percentile attribute PMAS threshold is met, although only 18% reduction is required to meet the median attribute.*

2.9 Load reductions

Load Duration Curves (LDCs) are the primary methodology used to calculate load reductions from inflows that may influence concentrations at CRE objective sites. Load Duration Curves are the combination of a Flow Duration Curve (FDC) and discrete contaminant loads calculated by multiplying the concentration of a contaminant (i.e., *E. coli*) with instantaneous flow (United States Environmental Protection Agency, 2007). The LDC method is established by the USEPA as a tool for developing contaminant load limits and estimating reductions to achieve them. The USEPA guide suggests the tool is more appropriate in situations where flow is the primary driver in pollutant delivery, and where an applicable water quality standard is relevant across the entire flow regime.

This method provides a useful indication of load reductions that are required to meet in-stream concentration targets, such as those specified in Tables 9 and 22 of Appendix 2 of the NPS-FM (MfE, 2020). An added benefit of this method is that exceedances of the concentration threshold are calculated across five flow bins, which can be used to differentiate between, and calculate load reductions for, different contributing flow bins that may be judged likely to come from different sources (e.g., exceedances at low flows are more likely from point-sources and exceedances at higher flows are more likely to be from diffuse sources). For the purpose of this report, load reductions are only discussed if the attribute statistic load breaches the guideline threshold across the entire flow record, i.e., if the attribute statistic (e.g., 95th percentile) breaches the load threshold (derived from the concentration threshold) at the median flow value (refer to Figure 6). This value is shown in load reduction tables in red text under the flow bin ‘All’. If there is an exceedance at this level, then the discussion within the text will refer to exceedances at each of the more refined flow bins.

The LDC approach assumes that contaminant concentrations are primarily driven by flow in each catchment of interest (United States Environmental Protection Agency, 2007). This is considered a valid assumption for *E. coli* contamination within agricultural catchments in New Zealand due to contaminant mobilisation processes associated with overland flow mechanisms (Howard-Williams et al., 2010). *E. coli* concentrations can also be influenced by other factors within these catchments, for example naturalised *E. coli* populations within sediment reservoirs (Pachepsky & Shelton, 2011), point source discharges from leaking sewerage infrastructure, or direct deposition hotspots (e.g., stock crossings or avian congregations), among others. However, in the absence of any information pertaining to these sources, it is assumed that faecal contamination from inflow catchments within this study are controlled by flow-related mechanisms. Caution should be applied for future studies to ensure that there are no large point source contributions within the catchment of interest that may interfere with the relationship between contaminant concentrations and flow. Flow concentration plots for each LDC site have been included in Appendix 2 for reference purposes. In general, these show reasonable correlations between concentration and flow at each site, thereby justifying the use of the LDC method.

It should also be noted that load reductions from the LDC approach in this report provide an indication of the magnitude of faecal contaminant load reductions that are required to meet concentration guidelines at each site. These numbers are not intended to be used directly as hard limits in policy, but rather will inform policy makers of the size of the problem and the flow conditions in which the problem is most likely to occur.

The steps to calculating a LDC are as follows:

1 **Develop a FDC from hydrological data at the site of interest** – FDCs are a way of summarising a flow record using cumulative probability. FDCs plot log-flow against the percentage of time that a given flow value is exceeded (Figure 2). The figure can be read by intersecting the curve with a vertical line for the percent exceedance, and a horizontal line for the corresponding flow value. For example, the two dashed vertical lines in Figure 2 represent the 25^{th} and 75^{th} percentile flow values. In this case, 75% of the time flow at the site exceeds 0.53 m^3/s, and 25% of the time flow exceeds 2.06 m^3/s.

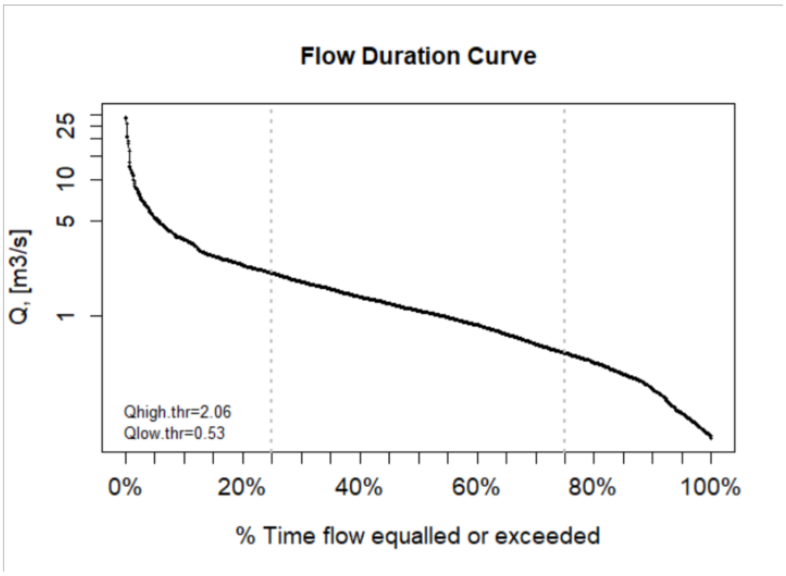

Figure 2 A flow distribution curve for a hypothetical hydrological site.

2 **Calculate the flow percentile for flow measured with each discrete water quality sample -** FDC's provide a useful summary of hydrological data, but they can also be turned into a mathematical function that calculates the flow percentile from a discrete flow value, or calculate the flow associated with a supplied percentile. In this case, the FDC is used to provide a flow percentile for each flow value (0=high; 100=low) that represents the flow conditions at the time of the sample.

3 **Calculate discrete contaminant loads for individual water quality samples –** This is a simple process of multiplying concentration by flow and a unit conversion. Loads for this analysis are typically expressed in contaminant unit/day (e.g., CFU/day).

4 **Plot contaminant loads against the flow percentile value –** This provides an overview of contaminant load delivery at different parts of the hydrograph (Figure 3). Typically, higher loads will be delivered at higher flows due to the increased volume of water being transported.

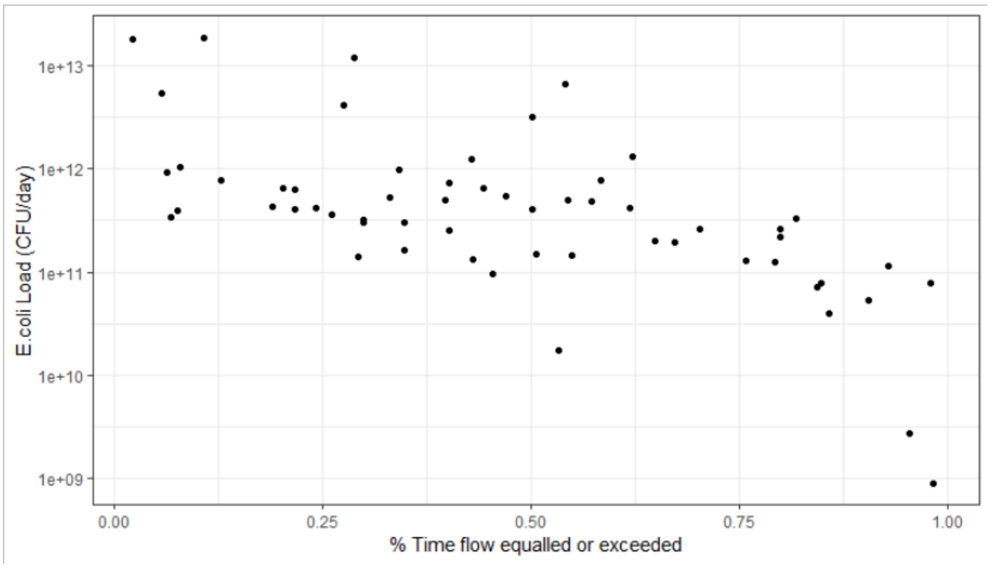

Figure 3 *E. coli loads from the subject site vs. the flow percentile value from the underlying FDC. The left of the figure represents high flow periods, and the right represents low flow periods.*

5 **Calculate and apply a guideline threshold to the LDC –** Guidelines can be any concentration value specified by a governing agency. Examples include the C/D (or red/alert) (550 CFU/100 ml) threshold for the Microbial Assessment Category (MAC) in the MWQG (MfE, 2003), suitability for primary contact criteria for Table 9 in Appendix 2A of the NPS-FM (i.e., blue, green, or yellow bands for each numeric attribute), or the national bottom line as specified in Table 22 of Appendix 2B of the NPS-FM (540 CFU/100 ml) (MfE, 2020). This analysis uses C/D thresholds from Table 9 and Table 22 of the NPS-FM, depending on the nature of the inflow site.

Guideline thresholds are added to the LDC by multiplying the concentration threshold by the corresponding FDC flow value for each percentile (0.00-1.00), and a unit conversion multiplier (Figure 4). Each load point that is above the brown line in Figure 4 will result in an in-stream concentration that exceeds the threshold (in this case the 550 CFU/100 ml MAC limit from the MWQG (MfE, 2003)).

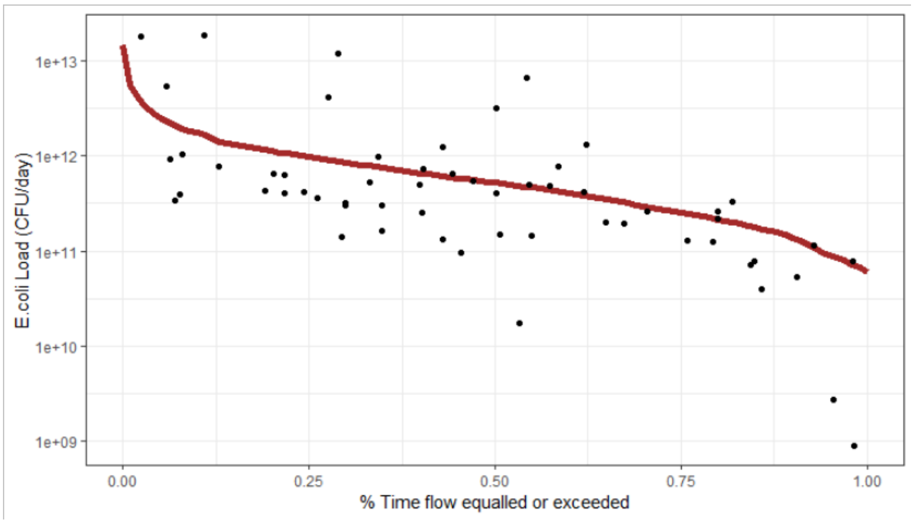

Figure 4 *The 550 CFU/100 ml guideline limit (brown line) added to the LDC.*

6 **Add flow bins to the LDC –** Flow bins are useful to split the FDC percentiles into categories where load reduction action is most needed. The US EPA (USEPA 2007) used the following flow bins:

- *High Flows = 0-0.1*
- *Moist Conditions = 0.1-0.4*
- *Mid-Range Flows = 0.4-0.6*
- *Dry Conditions = 0.6-0.9*
- *Low Flows = 0.9-1.0*

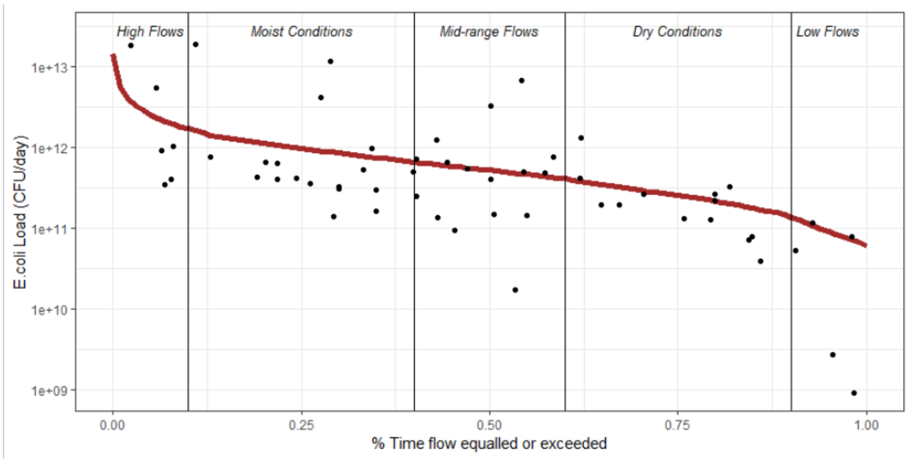

Figure 5 *Flow bins added to the LDC.*

7 **Calculate the statistic that relates to the guideline threshold –** This is dependent on the guideline, however Table 22 in the NPS-FM states that a 95th percentile is to be used. The 95th percentile of the example *E. coli* concentration dataset has been added to the plot in Figure 6. Guideline statistics usually do not differentiate between flows; therefore, the entire dataset is used (i.e. the guideline is assumed to apply at all times during all flows). When the entire dataset is assessed, the distance between the guideline statistic (red-dashed line) and the guideline limit (brown curve) at median flow (0.5) represents the overall load reduction that is required to meet the concentration guideline (red double-headed arrow). However, it can be seen in Figure 6 that the distance between the guideline statistic (red-dashed line) and guideline limit (brown curve) varies in different flow bins, and this is discussed in the next step.

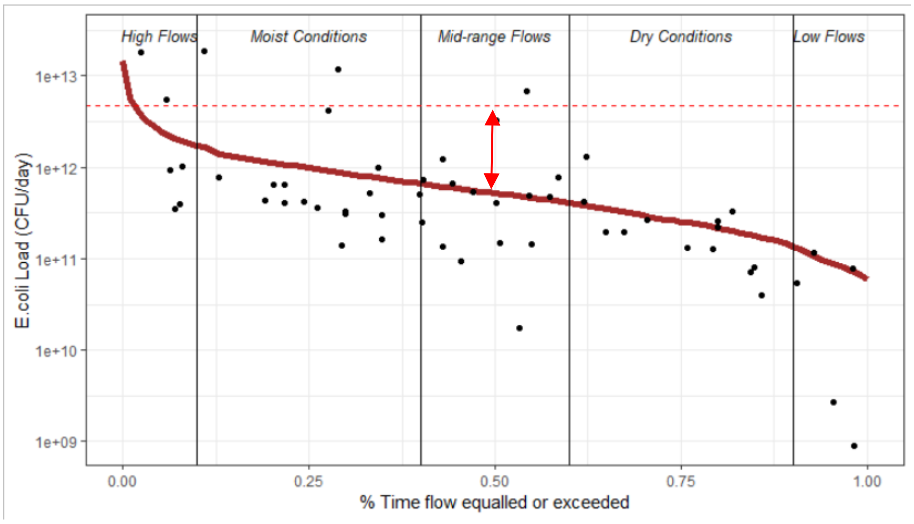

Figure 6 *The guideline statistic (horizontal, red-dashed line) added to the LDC. The red arrow represents the load reduction required for the sample population to meet the guideline threshold.*

8 **Calculate the guideline statistic for each flow bin –** The example in Figure 6 shows that loads typically meet the guideline at lower flows (Low – Dry) but exceed from mid-range upwards. Presenting the data in this way can be a useful diagnostic tool that helps point towards possible sources of the problem. For example, elevated loads at high flows are likely to be due to overland flow mobilising contaminants from surrounding agricultural land. However, elevated loads at low flows are more likely to be caused by point source contributions, such as stock crossings, birds nesting or broken sewerage lines, as overland pathways are not usually active. Applying the same management strategy within a catchment across all flow bins is likely to be inefficient as the problem is likely to be specific to only a few.

The differences in compliance between flow bins can be further explored by calculating the guideline statistic, and thus load reductions, for each flow bin, as depicted by the blue horizontal lines and double-headed arrows in Figure 7. The load reduction required for each flow bin is the difference between the guideline statistic and the guideline limit at the midpoint of the flow bin. This provides more nuanced results that can be used to inform more efficient policy and on-ground action. Figure 7 shows that, for this example, large load reductions are required for mid-range to high flow bins and smaller reductions for low-dry conditions. Loads can be enumerated in a table, and for the purposes of this report, are provided in the form of a percentage reduction. These percentage load reductions provide a diagnostic tool that allow catchment managers to make informed land management decisions.

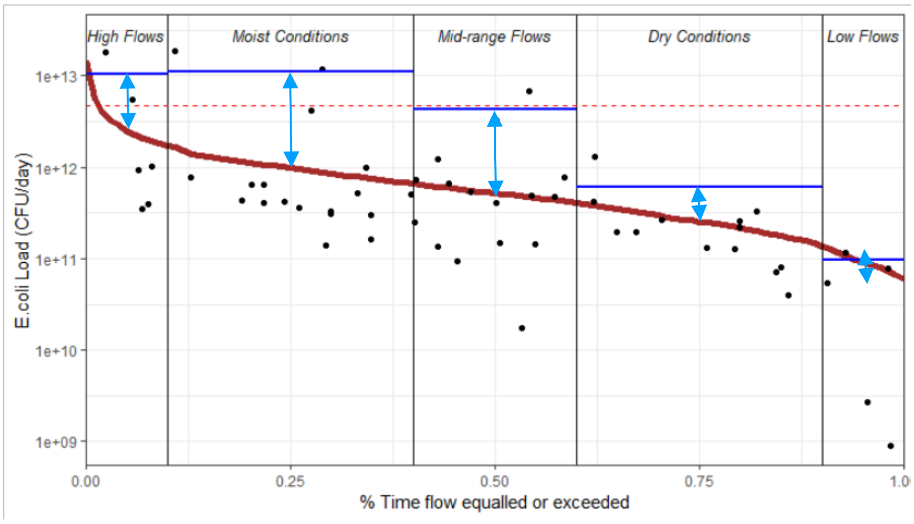

Figure 7 Guideline statistics added to the LDC for each flow bin.

Part 3:
Preliminary Assessment

Preliminary assessments do not consider Tangata Whenua or community aspirations which are yet to be collated. These may result in target state thresholds being set at more conservative levels than current PMAS thresholds, which are intended to represent thresholds similar to the national bottom set out in the NPS-FM, i.e., the worst state that an ecosystem should ever be maintained at. Re-assessment these data to incorporate community and Tangata Whenua aspirations will be addressed in separate analysis once this information becomes available.

3.1 Estuarine bathing sites

The preliminary assessment for estuarine bathing sites (using attribute Table 1) is shown in Table 3. This shows that all monitored estuarine bathing sites are in better condition than the PMAS, with Tauranga Harbour at Waimapu being the worst performing site with a 95th percentile of 323 CFU/100 ml. Therefore, none of these sites were progressed to the load reduction stage based on this assessment.

Table 3 Assessment of estuarine sites against the attribute table for primary contact in estuarine and coastal waters (Table 1).

Site Name	n	Enterococci (95th Percentile)	Band
Maketu at Surf Club	106	64	B
Ohiwa Harbour at Reserve (Boat Ramp)	95	73	B
Pilot Bay opposite Pacific Ave	109	135	B
Tauranga Harbour at Anzac Bay	110	96	B
Tauranga Harbour at Bowentown Boat Ramp	113	42	B
Tauranga Harbour at Maungatapu Bridge (Bathing)	108	109	B
Tauranga Harbour at Omokoroa Beach	109	27	B
Tauranga Harbour at Ongare Point	75	157	B
Tauranga Harbour at Pahoia Beach Road	72	226	C
Tauranga Harbour at Tanners Point Beach	109	124	B
Tauranga Harbour at Te Puna Waitui Reserve	109	112	B
Tauranga Harbour at Tilby Point	108	123	B
Tauranga Harbour at Waimapu Bridge	92	323	C
Waihi Estuary at Main Channel	107	174	B
Whakatane Heads	93	176	B

3.2 Coastal bathing sites

Table 4 shows the preliminary, current state assessment for coastal bathing sites (using attribute Table 1). This assessment resulted in all coastal bathing sites being graded a ‘B’ or better, with the worst performing site being Waiōtahe Beach at Surf Club with 91 CFU/100 ml. Overall, coastal sites performed better than estuarine sites, which was expected due to oceanic dilution and mixing. Based on this analysis, no open coastal sites were progressed to the load reduction stage of this report.

Table 4 Assessment of coastal sites against the primary contact in estuarine and coastal waters attribute table (Table 1).

Site Name	n	Enterococci (95th Percentile)	Band
Hikuwai Beach at end of Snell Road	108	70	B
Mount Maunganui at Surf Club	97	17	A
Ohope at Surf Club	95	92	B
Ohope Beach at Anne Street	95	15	A
Ohope Beach opposite Moana Street	95	8	A
Papamoa Beach at Harrison's Cut	96	32	A
Piripai at Ohuirehe Road	96	24	A
Pukehina at Surf Club	106	61	B
Te Kaha at Maraetai Bay	86	89	B
Waihi Beach at 3 Mile Creek	88	66	B
Waihi Beach at Surf Club	101	54	B
Waiotahe Beach at Surf Club	107	91	B
Whanarua at Whanarua Bay	86	44	B

3.3 Shellfish harvesting sites

Table 5 shows the preliminary, current state assessment for shellfish harvesting sites (using attribute Table 2). These sites are predominantly estuarine; however, some sites are situated on surf beaches (e.g., Ōhope at Surf Club). The shellfish harvesting attribute is deliberately more conservative than the recreational bathing attribute due to the potential harm caused by ingestion of contaminated shellfish flesh.

Of the 11 monitored shellfish harvesting sites, only two sites were graded a ‘Pass’, leaving nine sites (82%) that exceeded the PMAS. Of the nine sites, four (44%) exceeded the PMAS for both thresholds, while five (56%) breached only the 43 CFU threshold (<10% of samples can exceed).

Table 5 Assessment of shellfish harvesting sites against the shellfish harvesting attribute table (Table 2).

Name	n	Faecal Coliform (Median)	Faecal Coliform (%exceedance 43 CFU)	Band
Maketu at Surf Club	104	13	23.1	Fail
Ohiwa Harbour at Reserve (Boat Ramp)	92	6	14.1	Fail
Ohope at Surf Club	92	3	5.4	Pass
Ohope Beach opposite Moana Street	93	1	2.2	Pass
Tauranga Harbour at Anzac Bay	89	17	28.1	Fail
Tauranga Harbour at Bowentown Boat Ramp	112	8	15.2	Fail
Tauranga Harbour at Te Puna Waitui Reserve	108	8	10.2	Fail
Tauranga Harbour at Tilby Point	107	25	33.6	Fail

Name	n	Faecal Coliform (Median)	Faecal Coliform (%exceedance 43 CFU)	Band
Waihi Beach at 3 Mile Creek	87	6	17.2	Fail
Waihi Estuary at Main Channel	106	52	51.9	Fail
Waiotahe at Estuary	105	37	43.8	Fail

3.4 Sites requiring improvement

The preliminary assessment resulted in nine CRE objective sites that exceeded the PMAS, all of which were shellfish harvesting sites (Table 6). These sites require an improvement in the concentration of faecal coliforms at the harvesting sites, which is likely sourced contributed to by faecal coliform loads from local freshwater inflows and poorly maintained local infrastructure, as well as miscellaneous estuarine or oceanic inputs (e.g., avian inputs, piscine inputs, naturalised populations). Potential contributing sources are also listed in Table 6, although more detail will be provided in Part 4 of this report.

Table 6 Sites that require improvement to meet the shellfish harvesting attribute PMAS. This table outlines potential contributing sources for each of these sites. 'Misc' sources include those that are not derived from freshwater or oceanic inflows or poorly maintained infrastructure. Examples include avian inputs, piscine inputs, naturalised populations, discharges from boats etc.

Name	Potential Contributing Sources
Maketu at Surf Club	• Kaituna Catchment • Misc Estuarine
Ohiwa Harbour at Reserve (Boat Ramp)	• Nukuhou Catchment • Misc Estuarine • Local Septic • Local Urban
Tauranga Harbour at Anzac Bay	• Misc Oceanic • Local Septic • Misc Estuarine • Waiau Catchment • Tuapiro Catchment
Tauranga Harbour at Bowentown Boat Ramp	• Waiau Catchment • Local Urban • Misc Estuarine
Tauranga Harbour at Te Puna Waitui Reserve	• Te Puna Catchment • Local Urban • Misc Estuarine
Tauranga Harbour at Tilby Point	• Wairoa Catchment • Local Urban • Misc Estuarine
Waihi Beach at 3 Mile Creek	• Three Mile Creek • Misc Oceanic
Waihi Estuary at Main Channel	• Pongakawa • Wharere • Kaikokopu • Pukehina • Misc Estuarine • Local Urban
Waiotahe at Estuary	• Waiōtahe Catchment • Misc Estuarine

Part 4:
Site Specific Load Reductions

Waihī Beach

4.1 Waihī Beach at Three Mile Creek

4.1.1 Contaminant sources

The Waihī Beach at 3 Mile Creek shellfish harvesting site is located where Three Mile Creek flows into the surf zone at Waihī Beach, in the northern Bay of Plenty (Figure 8). This site is likely to be heavily influenced by the Three Mile Creek inflow which contains the Waihī Sewage Plant and has a predominant pastoral land use. Consents are held by Western Bay of Plenty District Council to discharge dairy effluent to ground soakage and to discharge treated sewage effluent to land. Contamination from oceanic sources is possible, but less likely seeming that coastal bathing and shellfish sites monitored by BOPRC typically have the lowest concentrations of all sites (Dare, 2020). This site is beyond the extent of the Tauranga Harbour hydrodynamic model so estimates of relative source contribution are unavailable.

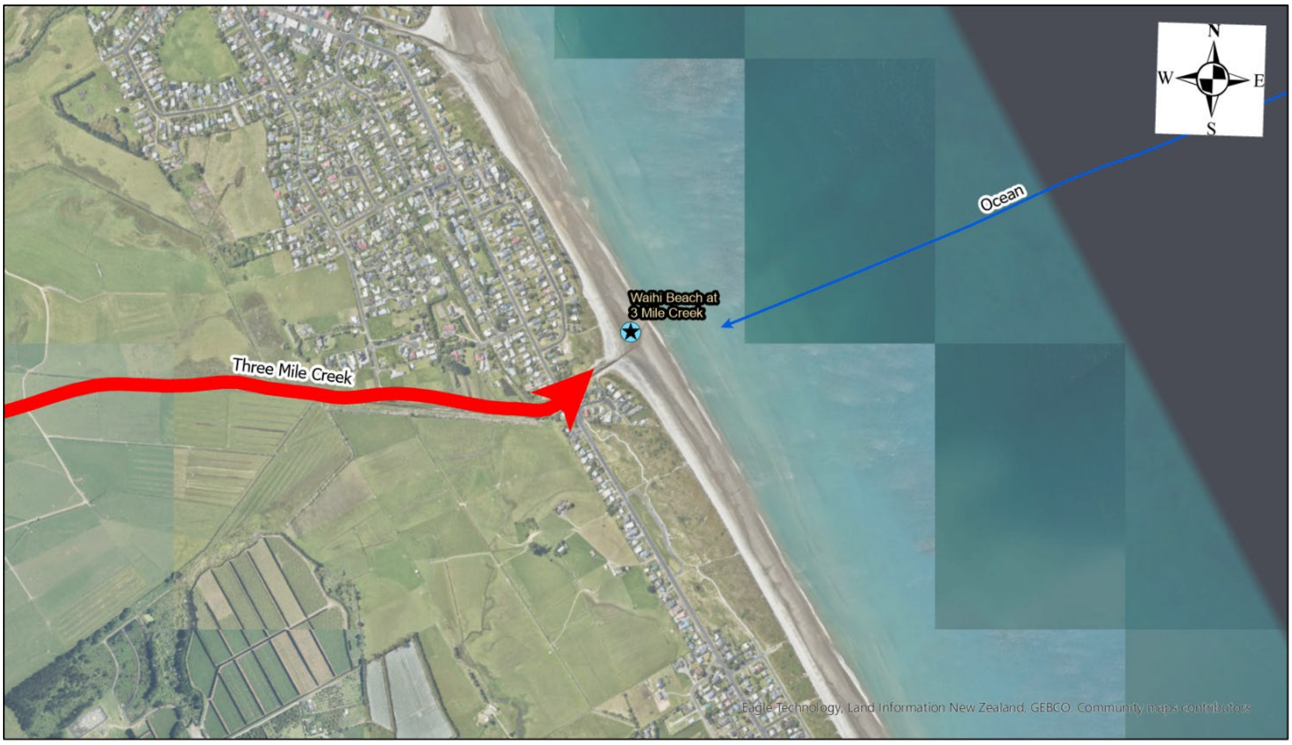

Figure 8 The location of the Waihī Beach at 3 Mile Creek shellfish harvesting site. The red line represents Three Mile Creek which is likely to be the dominant source of faecal contamination at this site, and the blue line represents potential oceanic influences.

4.1.2 Required concentration reduction

The cumulative distribution of faecal coliform concentrations collected at the Three Mile Creek shellfish harvesting site over the most recent five bathing seasons is represented by the red line (Reduction_0) in Figure 9. This shows that the median faecal coliform value (6 CFU/100 ml) is below the 14 CFU/100 ml threshold, however, the second threshold is exceeded where 17% of samples exceed the 43 CFU/100 ml threshold compared to the allowable 10%.

The blue line shows a simple reduction calculation that would allow the current distribution to meet the 10% (90th percentile) limit. This suggests that a 41% concentration reduction at the site would allow the current distribution of concentration values to meet both shellfish harvesting thresholds.

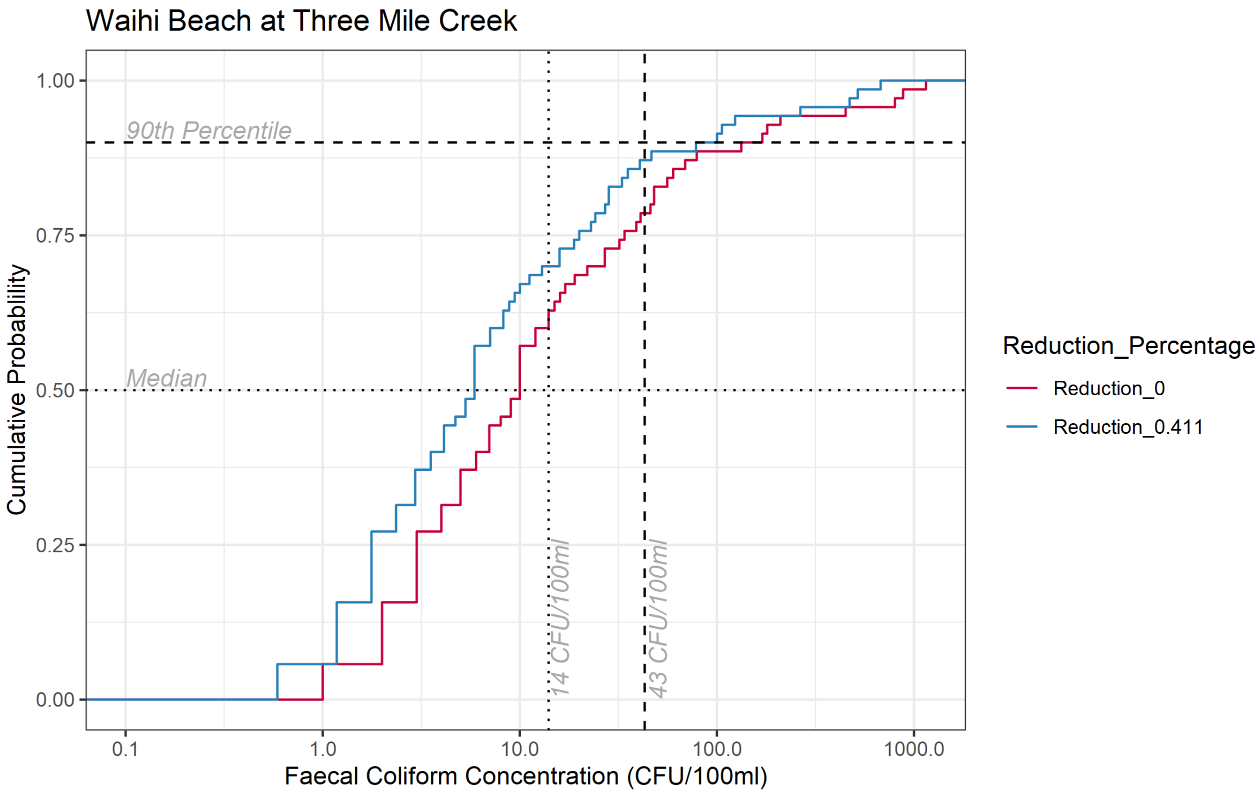

Figure 9 *Cumulative probability of Faecal Coliform concentrations at the Waihī Beach at Three Mile Creek shellfish harvesting site. The red line shows the current distribution (0% reduction), and the blue line shows a modified distribution that would meet the 90th percentile threshold (43 CFU/100 ml). Corresponding percentage concentration reductions can be obtained from the legend.*

4.1.3 Load reduction

Monitoring within Three Mile Creek consists of consent monitoring and a number of ad-hoc samples. There is currently no reliable flow information to calculate contaminant loads or load reductions

4.1.4 Knowledge to date

- The Waihī Beach at Three Mile Creek shellfish harvesting site exceeds the 43 CFU/100 ml (90th percentile) concentration threshold and requires a concentration reduction of approximately 41% to meet both PMAS thresholds and be deemed safe for human harvesting activities.
- The harvesting site is located at the mouth of Three Mile Creek which is likely to be the predominant source of faecal contamination at the shellfish harvesting site.
- Three Mile Creek has a wastewater treatment plant as well as a significant proportion of agricultural land use. Consent information suggests that this inflow has been a problem in the past, and there is currently a health warning advising against the harvest of shellfish from the area.

4.1.5 Knowledge gaps

- Concentration data within Three Mile Creek is historical, ad-hoc, or consent related, making it difficult to understand the current conditions that are impacting the shellfish harvesting site.
- There is no flow information with which to calculate load export from the Three Mile catchment. This could potentially be solved through a modelling exercise.
- There is no understanding of the flow conditions when the 43 CFU/100 ml threshold is typically breached.
- There is no information linking elevated Faecal Coliform concentrations in the water column at the shellfish harvesting site to elevated flesh concentrations.
- There is no faecal source tracing information, which may provide a better indication of whether contamination is coming from the Three Mile Creek catchment or local oceanic sources.

4.1.6 Recommended future work

1. This site would significantly benefit from alignment of faecal coliform concentration data at the shellfish site with coupled *E. coli* and flow data from Three Mile Creek. This information could be used to calculate load reductions, either via a LDC or simple dilution model.
2. Faecal source tracing information would also be useful to confirm the impact of Three Mile Creek on conditions at the shellfish harvesting site.

Tauranga Harbour

4.2 Tauranga Harbour at Anzac Bay

4.2.1 Contaminant sources

Tauranga Harbour at Anzac Bay is situated at the mouth of Tauranga Harbour, by the Bowentown heads (Figure 10). The Tauranga Harbour hydrodynamic particle tracer model showed that this site is heavily influenced by oceanic sources (62%) with local inflows making up the remaining contribution (Figure 11). Oceanic sources were largely dominated by outflow from the Waiau River, which, according to the hydrodynamic model, moved along the shoreline of Matakana Island before entering the northern section of the harbour through Bowentown heads. This finding, although interesting, needs validation before actions are put in place to limit contamination from southern harbour inflows for the purposes of addressing contamination at northern harbour sites.

Of the local inflows, the Waiau (11%) and Tuapiro Rivers (9%) were the largest contributors. There is a toilet block present at ANZAC bay which may also provide a source of local contamination, however this needs further investigation.

Figure 10 The location of the Tauranga Harbour at Anzac Bay shellfish harvesting site. Arrows indicate potential sources of faecal contamination to the shellfish site, with the size of the arrow representing the 'Overall' percentage contribution of that source to the site based on a hydrodynamic particle tracer model. Oceanic sources are the combination of all inflows from the southern part of Tauranga Harbour that exit the harbour at Mt Maunganui and re-enter the harbour at Bowentown Heads.

Although oceanic sources are shown to dominate at this site, 20% originated from local freshwater inflows. The Tuapiro River and Waiau River both contain NERMN monitoring sites with monthly sample collection. Data from each of these sites has been assessed against Appendix 2 of the NPS-FM (MfE, 2020) in Table 7. These results show that both sites exceed the threshold for swimmability which is defined as the C/D threshold. However, the Tuapiro site exceeds this threshold by an extremely small margin driven by the median statistic, while the Waiau site has much poorer results.

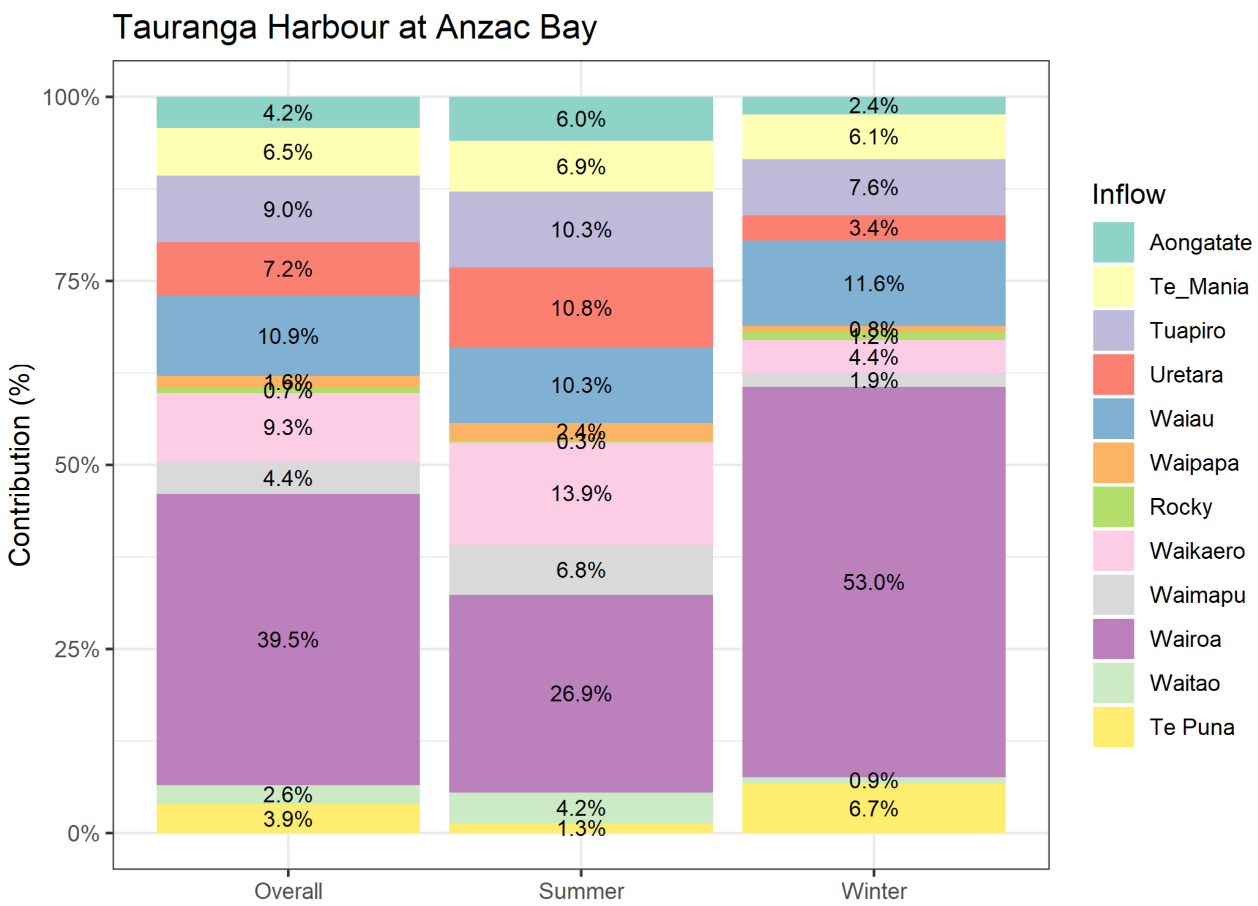

Figure 11 The percentage particle contribution at the Tauranga at Anzac Bay shellfish site, from each modelled Tauranga Harbour inflow, calculated using the DELWAQ particle transport model. Results are shown for 'Summer' and 'Winter' seasons and averaged into an 'Overall' category. Results are based on an inert particle tracer model where the initial concentrations from each inflow have been scaled to reflect median E. coli concentrations.

Table 7 Attribute statistics and grades for NERMN sites on the major inflows to the northern part of Tauranga Harbour, according to Table 9 in Appendix 2 of the NPS-FM.

Site	Attribute	Statistic	Current State	Statistic Band	Overall Band
Tuapiro at Hikurangi Road	*Escherichia coli*	Exceedance 260 (%)	26	B	D
		Exceedance 540 (%)	16	C	
		Median (5 year)	132	D	
		95th Percentile (5 year)	860	B	
Waiau at Waiau Road Ford	*Escherichia coli*	Exceedance 260 (%)	54	E	E
		Exceedance 540 (%)	28	D	
		Median (5 year)	330	E	
		95th Percentile (5 year)	4380	D	

4.2.2 Concentration reduction

Figure 12 shows the cumulative distribution of Faecal Coliform concentrations at the Tauranga Harbour at Anzac Bay shellfish harvesting site (red line), and the reductions required to meet the 90th percentile – 43 CFU/100 ml threshold (blue line) and the median - 14 CFU/100 ml threshold (green line). Assuming the distribution remains consistent as concentrations reduce (i.e., the shape remains the same), this analysis shows that concentrations need to reduce by 18% to meet the median threshold and 74% to meet the 90th percentile threshold.

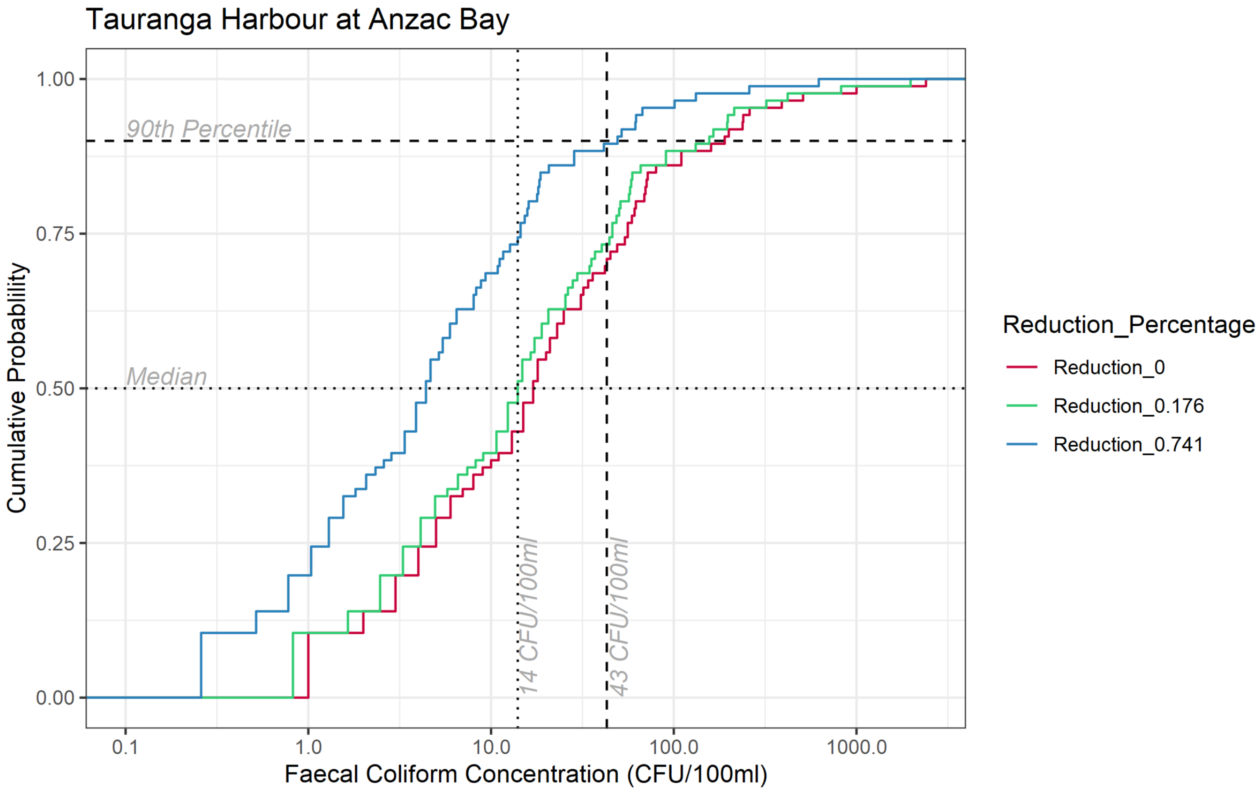

Figure 12 Cumulative probability of Faecal Coliform concentrations at the Tauranga Harbour at Anzac Bay shellfish harvesting site. The red line shows the current distribution (0% reduction), the green line shows a modified distribution that would meet the median value threshold (14 CFU/100 ml), and the blue line shows a modified distribution that would meet the 90th percentile threshold (43 CFU/100 ml). Corresponding percentage concentration reductions can be obtained from the legend.

4.2.3 Load reduction

The following analysis estimates the load reduction required for the two identified local inflows (Tuapiro and Waiau Rivers) to meet the swimmability requirements in Table 9 of the NPS-FM. It is assumed that these reductions will also improve conditions at the Anzac Bay shellfish site, although the hydrodynamic tracer model suggests that these inflows only make up around 20% of the overall contribution to the site.

Figure 13 shows the Load Duration Curve (LDC) for all four numeric attributes contained within Table 9 of the NPS-FM, at the Tuapiro at Hikurangi NERMN site. This plot shows that the median attribute (Figure 13-C) is the only attribute that requires a reduction to meet the swimmability criteria when I flow-bins are ignored (i.e., the red dashed line is above the brown curve), requiring an overall load reduction of 1%. Figure 13-C and Table 8 show that all flow bins, with the exception of the moist category, exceed the guideline requirements and are potential targets for *E. coli* load reductions (i.e., the blue lines are above the mid-point of the brown curve within each flow bin).

In general, Table 8 shows that the Tuapiro inflow requires a 1% load reduction in faecal coliforms to meet the swimmability target for all attribute statistics. It also provides diagnostic outputs that shows us that the site breaches three of the four attribute statistic targets during low flows, which may indicate a local point source input.

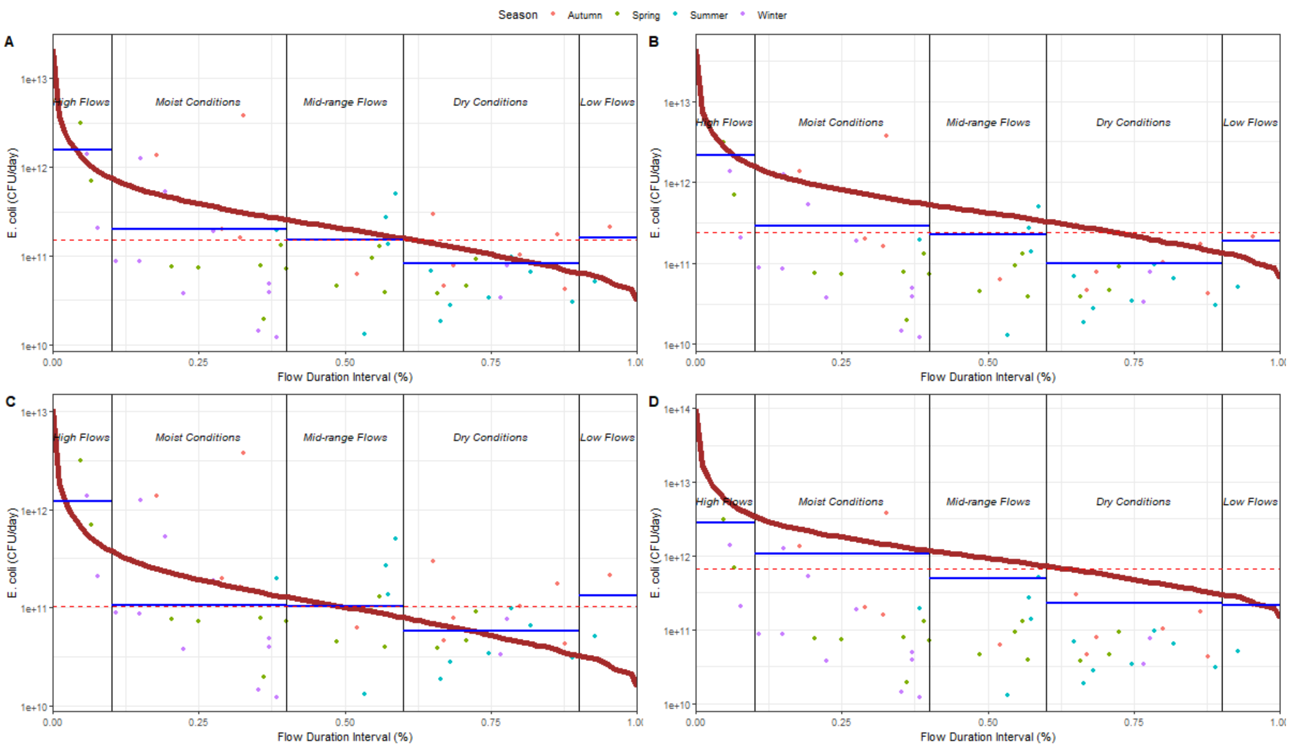

Figure 13 *Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Tuapiro at Hikurangi Road NERMN site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown curve represents the swimmability (C/D) threshold for each numeric attribute.*

Table 8 *Output for the LDC analysis for Tuapiro at Hikurangi Road showing load reductions (%) to meet guideline thresholds. The 'all' category is highlighted red and shows the overall load reduction required to meet the guideline threshold if flow-bins are ignored. Black text shows load reductions to meet the guideline threshold for each flow bin, which are independent of the 'all' calculation.*

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Tuapiro	Low	Exc260	68
Tuapiro	Dry	Exc260	0
Tuapiro	Mid-Range	Exc260	0
Tuapiro	Moist	Exc260	0
Tuapiro	High	Exc260	18

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Tuapiro	All	Exc260	0
Tuapiro	Low	Exc540	42
Tuapiro	Dry	Exc540	0
Tuapiro	Mid-Range	Exc540	0
Tuapiro	Moist	Exc540	0
Tuapiro	High	Exc540	0
Tuapiro	All	Exc540	0
Tuapiro	Low	Median	80
Tuapiro	Dry	Median	9
Tuapiro	Mid-Range	Median	3
Tuapiro	Moist	Median	0
Tuapiro	High	Median	48
Tuapiro	All	Median	1
Tuapiro	Low	Perc95	0
Tuapiro	Dry	Perc95	0
Tuapiro	Mid-Range	Perc95	0
Tuapiro	Moist	Perc95	0
Tuapiro	High	Perc95	0
Tuapiro	All	Perc95	0

Figure 14 and Table 9 shows the same LDC analysis from the Waiau River at Waiau Road NERMN site. This analysis reveals that all numeric attributes, aside from the percentage exceedance of 540 CFU/100 ml, exceed the swimmability threshold and require *E. coli* load reductions. These reductions range from 32% to meet swimmability for the percentage exceedance of 260 CFU/100 ml attribute, to a 59% reduction to meet the 95th percentile attribute. Reductions are split across all flow bins depending on the numeric attribute with significant reductions required at lower flows to meet the median attribute guideline, and large reductions at higher flows to meet the exceedance of 560 CFU/100 ml and 95th percentile attribute.

Load reductions for the Waiau River range from 32% to 59% depending on the numeric attribute, although a reduction of 59% is required to meet all four. Reductions generally need to be targeted across all flow bins for the median attribute, and higher flow bins for the exceedance of 540 CFU/100 ml and 95th percentile attributes.

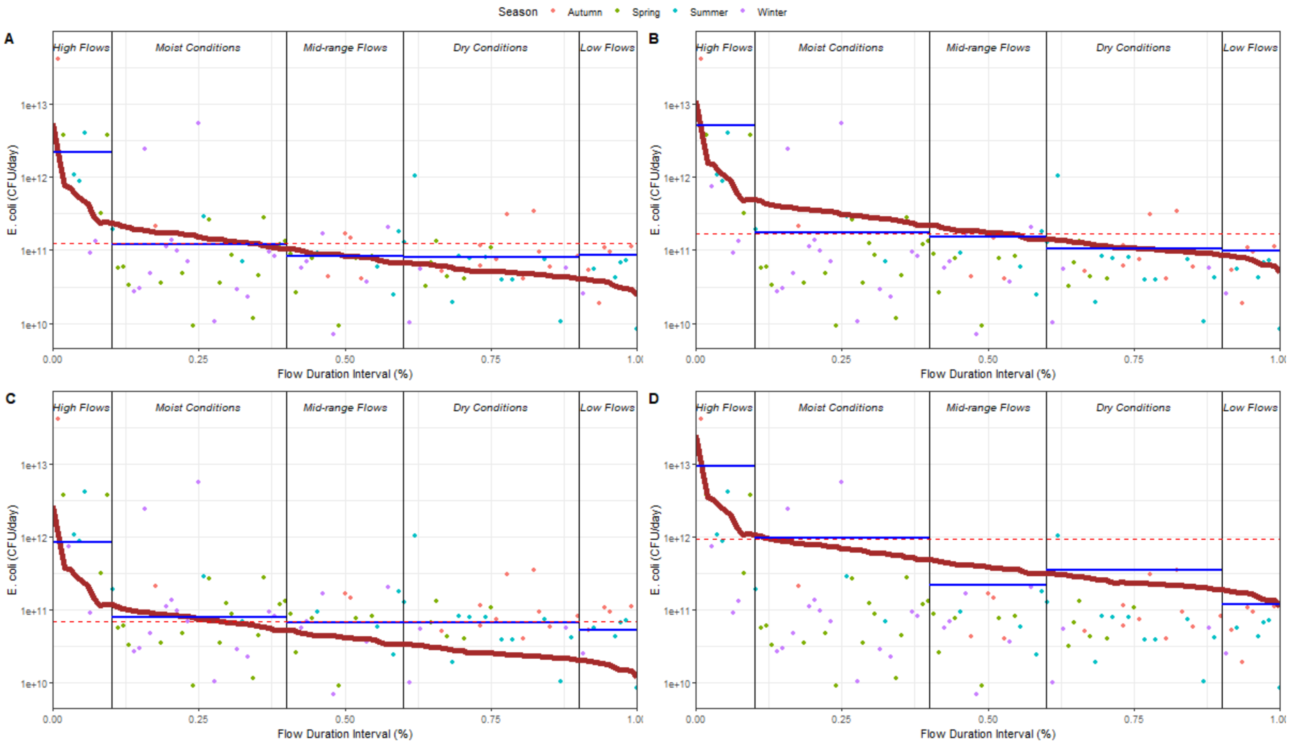

Figure 14 *Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Waiau River at Waiau Road Ford NERMN site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown curve represents the swimmability (C/D) threshold for each numeric attribute.*

Table 9 *Output for the LDC analysis for Waiau at Waiau Road Ford showing load reductions (%) to meet guideline thresholds. The 'all' category is highlighted red and shows the overall load reduction required to meet the guideline threshold if flow-bins are ignored. Black text shows load reductions to meet the guideline threshold for each flow bin, which are independent of the 'all' calculation.*

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Waiau	Low	Exc260	57
Waiau	Dry	Exc260	36
Waiau	Mid-Range	Exc260	0
Waiau	Moist	Exc260	0
Waiau	High	Exc260	78
Waiau	All	Exc260	32
Waiau	Low	Exc540	23
Waiau	Dry	Exc540	0
Waiau	Mid-Range	Exc540	0
Waiau	Moist	Exc540	0
Waiau	High	Exc540	80

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Waiau	All	Exc540	0
Waiau	Low	Median	66
Waiau	Dry	Median	62
Waiau	Mid-Range	Median	38
Waiau	Moist	Median	7
Waiau	High	Median	71
Waiau	All	Median	41
Waiau	Low	Perc95	0
Waiau	Dry	Perc95	32
Waiau	Mid-Range	Perc95	0
Waiau	Moist	Perc95	29
Waiau	High	Perc95	75
Waiau	All	Perc95	59

4.2.4 Knowledge to date

- The shellfish harvesting site has been shown to be influenced by local inflows: the Waiau River (11%) and the Tuapiro River (9%).
- The remaining dominant source comes from oceanic sources; however, this may include discharge from major inflows (e.g., Wairoa River 40%) in the southern section of Tauranga Harbour.
- Both inflows have *E. coli* concentrations that exceed the swimmability threshold within Table 9 of the NPS-FM.
- Faecal Coliform concentrations at the Anzac Bay site need to reduce by approximately 74% and 18% to meet the 90th percentile and median PMAS thresholds respectively.
- One of the major inflows, the Tuapiro River, exceeds the swimmability threshold slightly due to an elevated median statistic. Load reductions to make this site swimmable are small (1%) and can be addressed across all flow bins, although there appears to be a minor issue at lower flows which may warrant further investigation.
- The second major inflow, the Waiau River, exceeds three of the four numeric attributes and requires significant reductions to meet the swimmability threshold defined in the NPS-FM. Load reductions range from 31.6% to 58.5% depending on the numeric attribute and need to be targeted across all flow bins for the median attribute, and higher flow bins for the exceedance of 540 CFU/100 ml and 95th percentile attributes.

4.2.5 Knowledge gaps

- There is no information on the extent of influence that comes from estuarine sources, or local septic sources.
- Oceanic sources need to be verified before they can be linked to dominant southern harbour inflows, as suggested by model results.
- There is a lack of microbiological source tracing of faecal contamination at the shellfish harvesting site.
- There is no information relating to how water column concentrations translate to flesh concentration in harvested shellfish.

- There is no information regarding water column faecal concentrations over a tidal cycle.

4.2.6 Recommended future work

1 Faecal source tracing is a simple method that might help support the findings from the hydrodynamic model. If a ruminant source is identified at the shellfish harvesting site, then it suggests that contamination is coming from local inflows with agricultural catchments. Alternatively, detection of a human marker would suggest local septic inputs.

4.3 Tauranga Harbour at Bowentown Boat Ramp

4.3.1 Contaminant sources

The Tauranga Harbour at Bowentown Boat Ramp shellfish harvesting site is located near the fishing club at the end of Pio Road. Hydrodynamic modelling results suggest that this site is directly influenced by the Waiau River (76%; Figure 15 and Figure 16) which flows from the foothills of the Kaimai Range, through Athenree into Tauranga Harbour. The Waiau River has high levels of faecal contamination resulting in an 'E' grading for the NPS-FM (Table 7).

An attempt was made to link monitoring results from the Waiau River at Waiau Road NERMN site and the Tauranga Harbour at Bowentown Boat Ramp site, however, there were only four samples collected from each site on coinciding days (Figure 17). These broadly suggest that elevated results in the Waiau River result in elevated results at the shellfish harvesting site, however there is not enough data to state this conclusively. Results at the shellfish harvesting site are also predicted to be influenced by oceanic sources (14% site contribution) and the Tuapiro River inflow (4%), and could also be influenced by local estuarine sources, or leaking sewerage and wastewater infrastructure from the local Bowentown community.

Figure 15 The location of the Tauranga Harbour at Bowentown Boat Ramp shellfish harvesting site. The light blue line represents the flow path of the Waiau River at low tide.

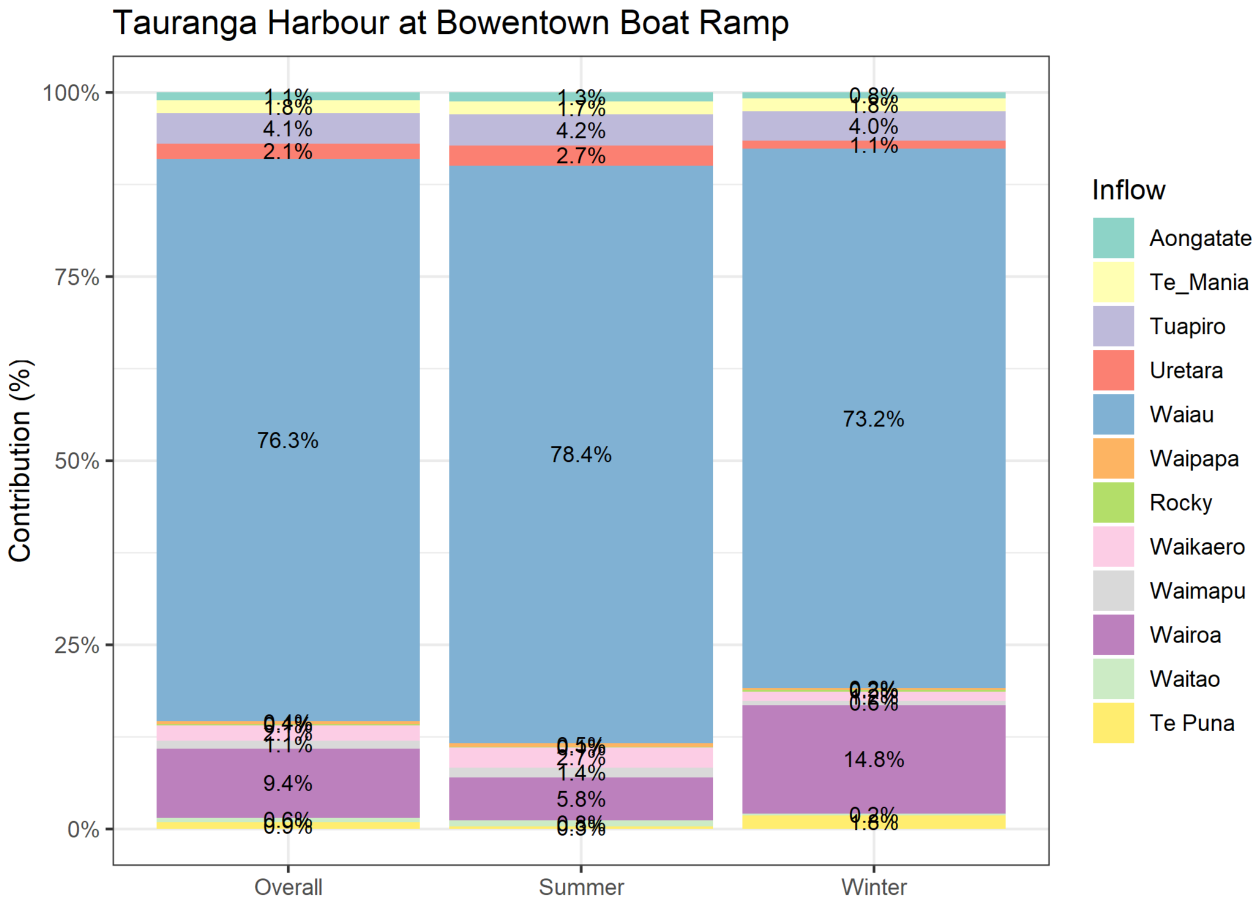

Figure 16 *The percentage particle contribution at the Tauranga Harbour at Bowentown Boat Ramp shellfish site, from each modelled Tauranga Harbour inflow, calculated using the DELWAQ particle transport model. Results are shown for 'Summer' and 'Winter' seasons and averaged into an 'Overall' category. Results are based on an inert particle tracer model where the initial concentrations from each inflow have been scaled to reflect median E. coli concentrations.*

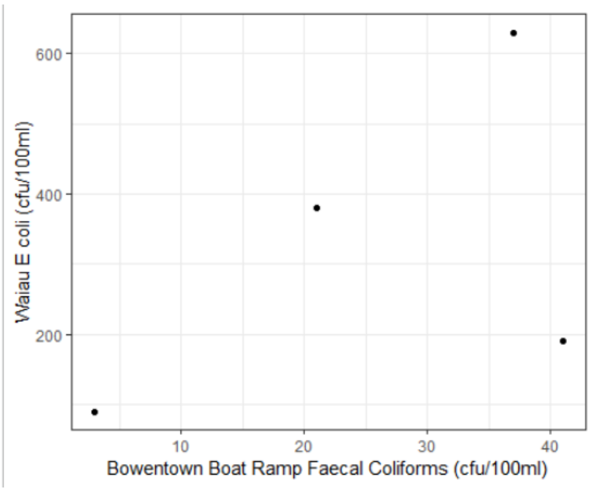

Figure 17 *Samples from the Waiau River at Waiau Road NERMN site and the Tauranga Harbour at Bowentown Boat Ramp shellfish harvesting site with coinciding sample dates.*

4.3.2 Concentration reduction

Figure 18 shows the cumulative distribution of Faecal Coliform concentration results at the Bowentown Boat Ramp shellfish harvesting site. This figure shows that the current distribution (red line) meets the median threshold of 14 CFU/100 ml but exceeds the 90th percentile threshold of 43 CFU/100 ml. Assuming the distribution remains consistent as concentrations reduce (i.e., the shape remains the same), this analysis shows that concentrations need to reduce by 26% to meet the 90th percentile threshold.

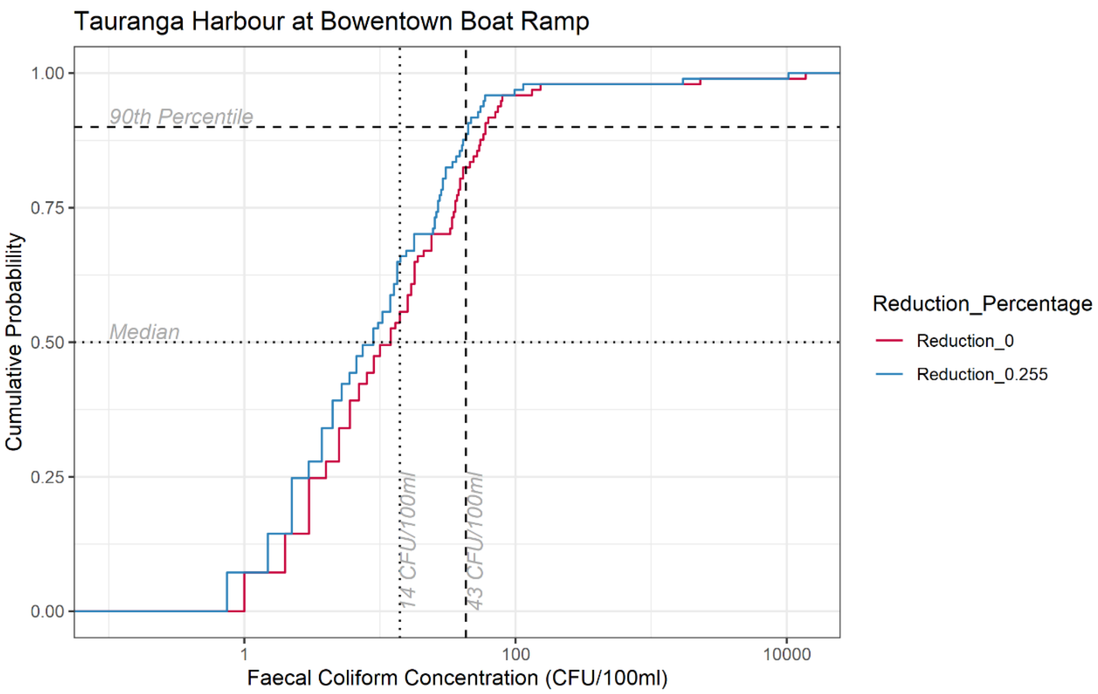

Figure 18 *Cumulative probability of Faecal Coliform concentrations at the Tauranga Harbour at Bowentown Boat Ramp shellfish harvesting site. The red line shows the current distribution (0% reduction), and the blue line shows a modified distribution that would meet the 90th percentile threshold (43 CFU/100 ml). Corresponding percentage concentration reductions can be obtained from the legend.*

4.3.3 Load reduction

Hydrodynamic modelling results suggest that improvement in the state of the Waiau River will result in improved conditions at the Bowentown Boat Ramp shellfish site.

Load reductions for the Waiau River are outlined in Figure 14 and Table 9, and imply that reductions in the order of 59% are required to meet swimmability criteria for all numeric attributes.

4.3.4 Knowledge to date

- The Bowentown Boat Ramp shellfish harvesting site is dominated by the Waiau River (76%) which runs from the foothills of the Kaimai Ranges.
- Other notable sources include oceanic water (14%) and the Tuapiro River (4%).
- Concentrations at the shellfish harvesting site meet the median threshold but exceed the 90th percentile threshold.
- Four samples seem to indicate that there is some relationship between elevated concentrations on the Waiau River and concentrations at the Bowentown Boat Ramp site. However more information is needed to confirm this.
- The Waiau River is rated 'E' against Table 9 in the NPS-FM due to an elevated median concentration and large proportion of samples over 540 CFU/100 ml.

4.3.5 Knowledge gaps

- It is not known how elevated *E. coli* conditions on the Waiau River influence Faecal Coliform concentrations at the shellfish harvesting site.
- There is no information on local estuarine sources or sources from local septic systems.
- There is a lack of microbiological source tracing data for faecal contamination at the shellfish harvesting site.
- There is no information regarding water column concentrations over a tidal cycle.
- There is no information regarding how water column concentrations translate to flesh concentration in harvested shellfish.

4.3.6 Recommended future work

1. Results from the hydrodynamic model could by supported by paired sampling between the shellfish harvesting site and the Waiau NERMN site. This would provide a relationship between the two sites.
2. Sampling over a tidal cycle at the shellfish harvesting site may also provide clarity around when contaminated water is present.
3. Shellfish flesh sampling may be useful to determine if elevated water column concentrations are translated into flesh concentrations.

4.4 Tauranga Harbour at Te Puna Waitui Reserve

4.4.1 Contaminant sources

The Tauranga Harbour at Te Puna Waitui Reserve site is dominated by the Te Puna Stream (50%) which flows directly past the site (Figure 19 and Figure 20). The Te Puna Stream does not contain a routine monitoring site, so it is difficult to assess the level of faecal contamination coming from this inflow. However, there are eight ad-hoc *E. coli* samples from the SH2 bridge collected between May 2019 and January 2020 (Figure 21). These results suggest that the stream has an elevated median concentration (345 CFU/100 ml) and is subject to high extreme concentrations of *E. coli,* with the highest value recorded at 2600 CFU/100 ml. More information is needed to be certain of these concentrations, but it can be assumed that there is a significant faecal load originating from this source.

Other sources include the Wairoa River (32%), miscellaneous estuarine sources, and local septic inputs from fringing rural developments. Regarding the latter, several Te Puna drains were found to have faecal contamination problems of a human source prior to the community reticulation of septic tanks in 2017 (Scholes, 2018b). Since community reticulation, contamination levels have reduced significantly and no human markers have been found (Scholes, 2020).

Figure 19 The location of the Tauranga Harbour at Te Puna Waitui Reserve shellfish harvesting site. The yellow line represents the flow path of the Te Puna Stream at low tide. The purple and grey lines represent the flow path of the other two inflows that contribute to the Te Puna Waitui site.

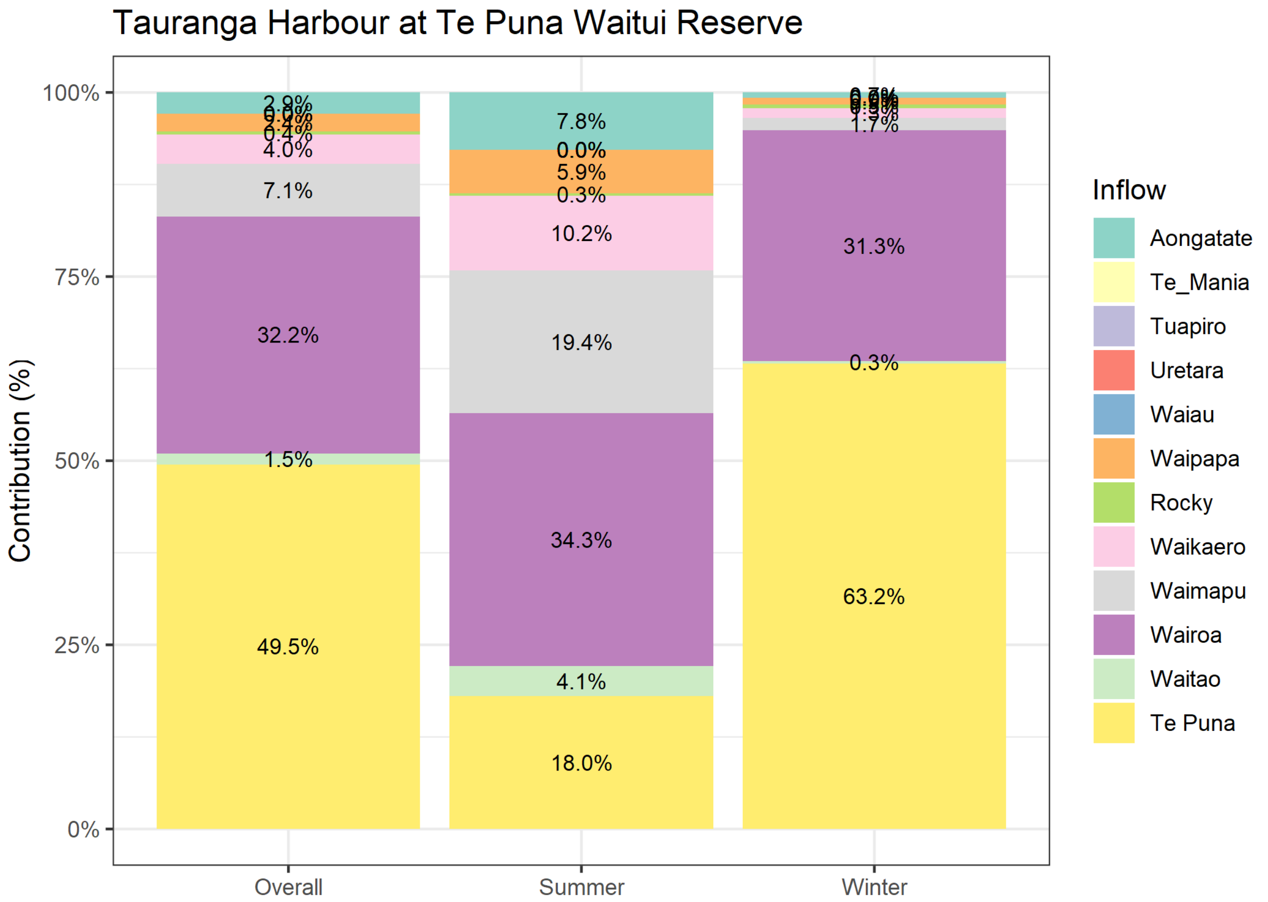

Figure 20 The percentage particle contribution at the Tauranga Harbour at Te Puna Waitui Reserve shellfish site, from each modelled Tauranga Harbour inflow, calculated using the DELWAQ particle transport model. Results are shown for 'Summer' and 'Winter' seasons and averaged into an 'Overall' category. Results are based on an inert particle tracer model where the initial concentrations from each inflow have been scaled to reflect median E. coli concentrations.

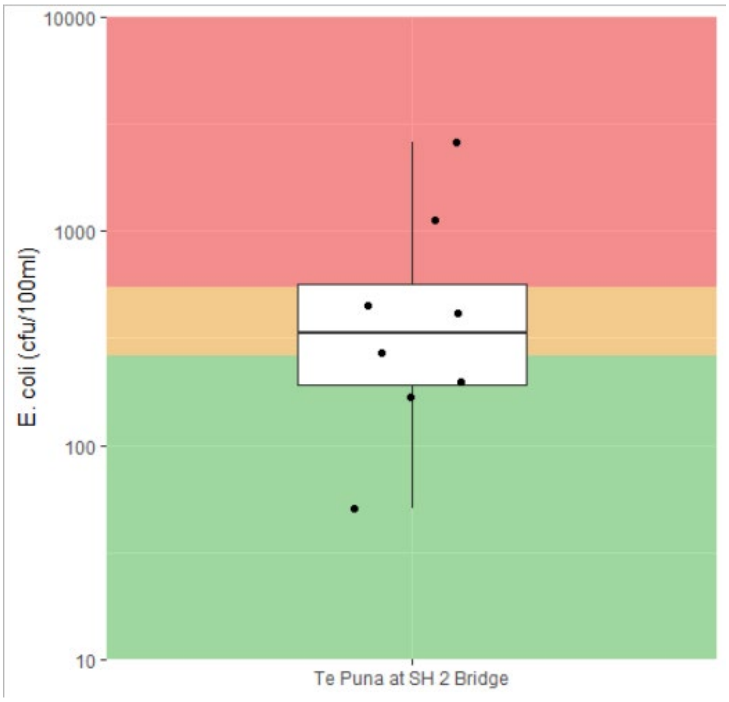

Figure 21 E. coli concentrations collected at an ad-hoc sampling site on the Te Puna Stream. The coloured background represents the traffic light system in the MWQG, where results less than 260 CFU 100 ml are deemed 'green', 260-550 CFU/100 ml are 'amber' and results over 550 are 'red' and therefore unswimmable.

4.4.2 Concentration reduction

The Tauranga Harbour at Te Puna Waitui Reserve shellfish harvesting site meets the median threshold of 14 CFU/100 ml and is extremely close to the 90th percentile threshold of 43 CFU/100 ml. In fact, the 90th percentile value calculated as a percentage of samples greater than 43 CFU/100 ml is equal to 10%, while the 90th percentile number calculated through application of a quantile model function is equal to 41.4 CFU/100 ml. This means that any calculated concentration reductions are likely to be within the margin of error.

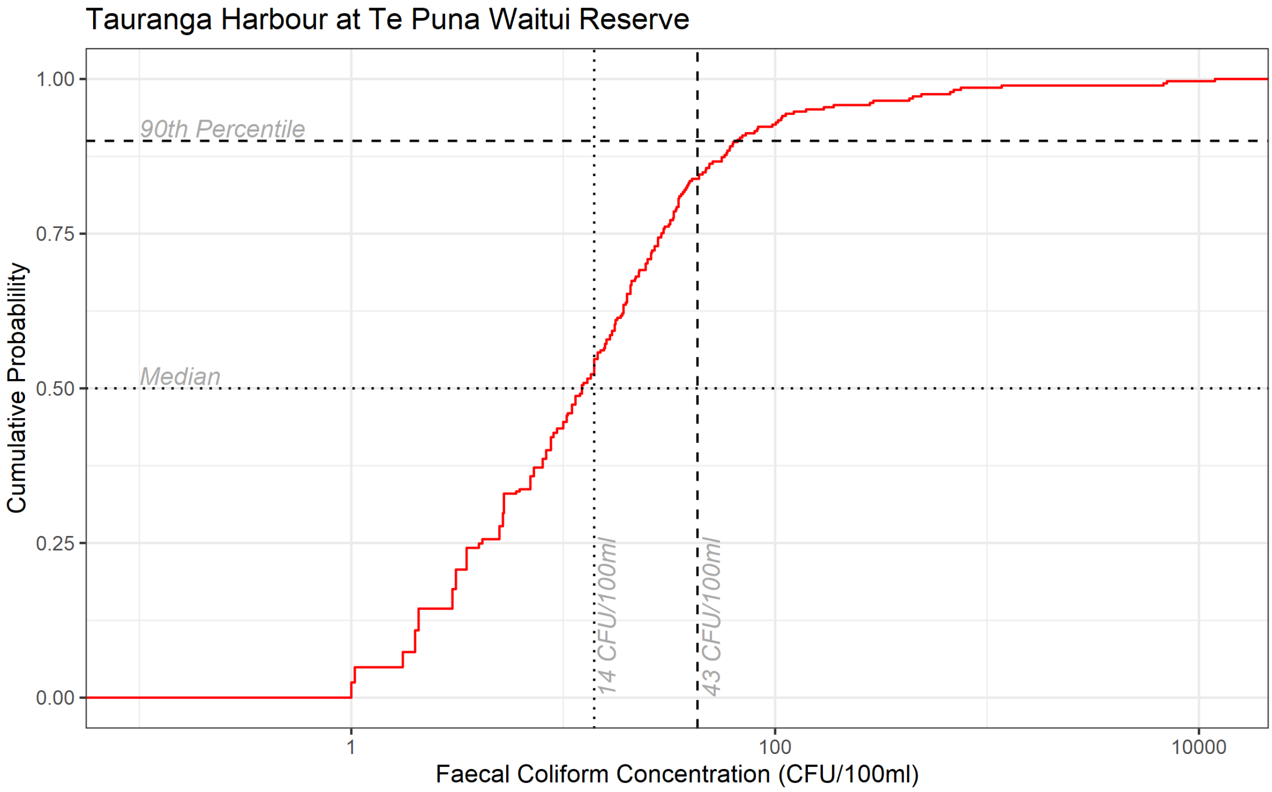

Figure 22 Cumulative probability of Faecal Coliform concentrations at the Tauranga Harbour at Te Puna Wautui Reserve shellfish harvesting site.

4.4.3 Load reduction

It is unnecessary to quantify load reductions for this shellfish site given the margins of error associated with the faecal coliform distribution. Regardless, improvements within the Te Puna Stream catchment are highly likely to benefit the Te Puna Waitui shellfish harvesting site through reduced faecal load export.

4.4.4 Knowledge to date

- The Te Puna Waitui shellfish harvesting site is extremely close to the PMAS 90th percentile threshold and is therefore considered within the margin of error of statistical models applied to the dataset.
- Modelling shows that the Te Puna Stream has a significant impact upon the shellfish harvesting site.
- The Te Puna Stream has limited water quality information, but there are eight samples that suggest that faecal contamination may be elevated. The median value of these samples equalled 345 CFU/100 ml, and the maximum value was over 2500 CFU/100 ml.
- Fairly recent reticulation of the Te Puna sewerage system has reduced overall contamination of drains feeding into the mainstem river and has eliminated evidence of human source markers.

4.4.5 Knowledge gaps

- There is a lack of a *E. coli* concentrations and flow data in the Te Puna Stream.
- There is no information on how the Te Puna Stream influences concentrations at the shellfish harvesting site.

- There is a lack of data linking Faecal Coliforms in the water column at the shellfish harvesting site and *E. coli* in the flesh of shellfish.

4.4.6 Recommended future work

This site is a lower priority than other sites given how close Faecal Coliform concentrations at the shellfish harvesting site are to the 43 CFU/100 ml (90th percentile) threshold in the MWQG.

1. However, it would be beneficial to collect *E. coli* concentrations from the Te Puna Stream on the same day that Faecal Coliform concentrations are collected from the shellfish harvesting site. This would provide a simple way to link concentrations in the Te Puna Stream with concentrations at the shellfish harvesting site.
2. Faecal source tracing at the shellfish harvesting site would also be a simple way to gain insight into faecal sources at the shellfish harvesting site.

4.5 Tauranga Harbour at Tilby Point

4.5.1 Contaminant sources

The Tauranga Harbour at Tilby Point shellfish harvesting site is located near Fergusson Park in Matua. This area is strongly influenced (94%) by the largest inflow to Tauranga Harbour, the Wairoa River (Figure 23 and Figure 24), which wraps around Tilby point before joining the main harbour channels. Other potential sources include local estuarine sources (e.g., aggregations of birds etc.) and potential inputs from sewerage and wastewater infrastructure on the Matua peninsula.

The Wairoa River has numerous routine sampling sites, including the bottom of catchment recreational bathing and NERMN water quality site 'Wairoa River at SH2'. These sites are rated a 'D' according to Table 9 in Appendix 2A of the NPS-FM, and 'Poor' with regard to Table 22 in Appendix 2B (Table 10 and Table 11). Both grades are deemed not suitable for human recreation.

Figure 25 shows the relationship between *E. coli* concentrations at the Wairoa River at SH2 bathing/NERMN site and Faecal Coliforms at the Tilby Point shellfish harvesting site. This figure shows that there is a lot of variability at lower concentrations, presumably because the impact of the faecal signal from the Wairoa River is less than that of local sources. However, when the Wairoa River has concentrations above 100 CFU/100 ml, there appears to be a moderate to strong relationship with Faecal Coliforms at the shellfish harvesting site. Overall *E. coli* concentrations on the Wairoa River explain 43% of the variability at the Tilby Point shellfish harvesting site.

Two faecal source tracking samples have been processed at the Tilby Point shellfish harvesting site thus far (December 2021 and January 2022), with results revealing positive markers for dog and avian sources (ESR, 2022). Both of these samples were collected on days when the Wairoa River had low-moderate flow, implying that sources were most likely local.

Figure 23 The location of the Tauranga Harbour at Tilby Point shellfish harvesting site. The purple line represents the flow path of the Wairoa River at low tide.

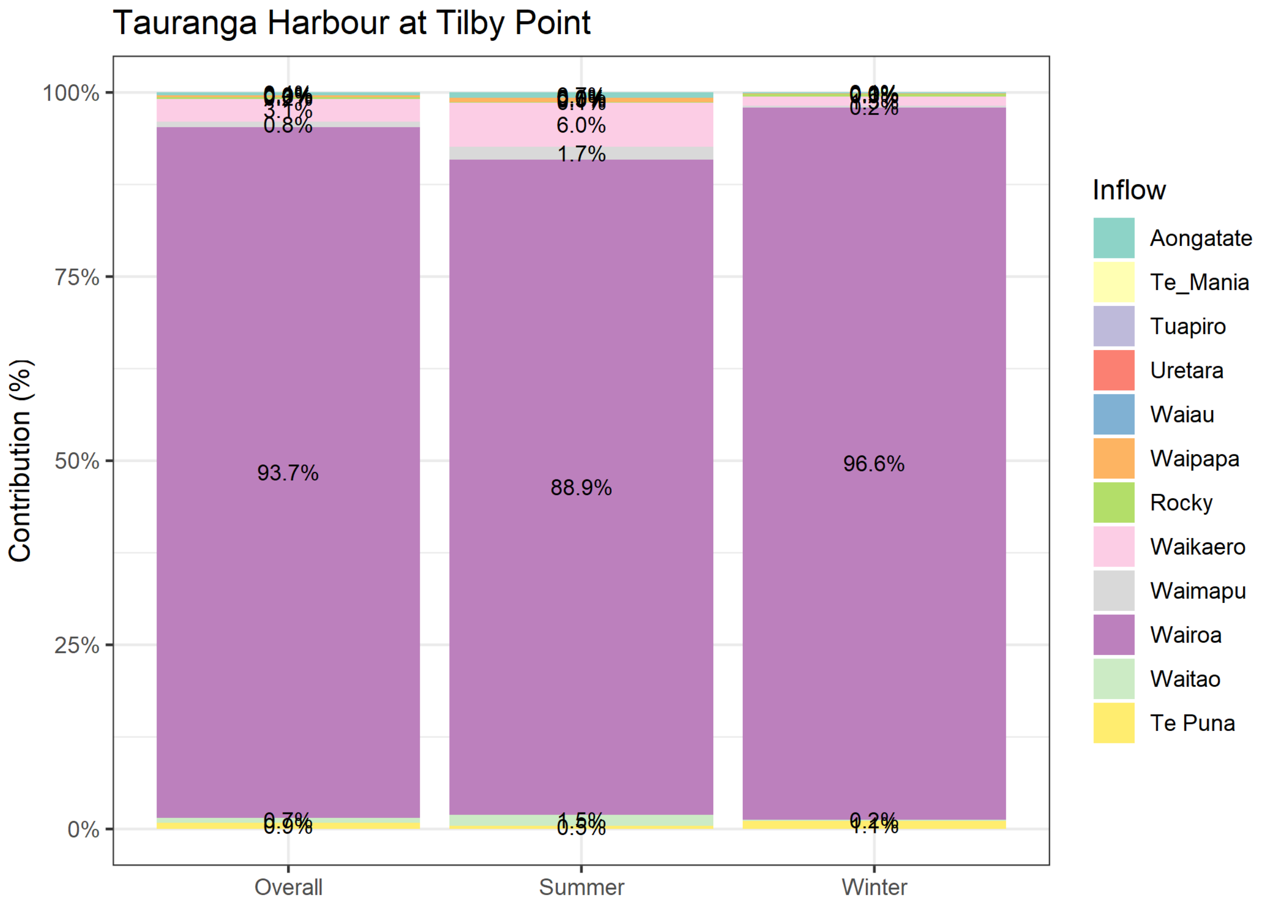

Figure 24 The percentage particle contribution at the Tauranga Harbour at Tilby Point shellfish site, from each modelled Tauranga Harbour inflow, calculated using the DELWAQ particle transport model. Results are shown for 'Summer' and 'Winter' seasons and averaged into an 'Overall' category. Results are based on an inert particle tracer model where the initial concentrations from each inflow have been scaled to reflect median E. coli concentrations.

Table 10 Attribute statistics and grades for the Wairoa at SH2 NERMN water quality site, according to Table 9 in Appendix 2A of the NPS-FM.

Site	Attribute	Statistic	Current State	Statistic Band	Overall Band
Wairoa at SH2	E. coli (Table 9)	Exceedance 260 (%)	28	B	D
		Exceedance 540 (%)	16	C	
		Median (5 year)	90	A	
		95th Percentile (5 year)	3860	D	

Table 11 *Attribute statistics and grades for the Wairoa at SH2 NERMN recreational bathing site, according to Table 22 in Appendix 2B of the NPS-FM.*

Site	Attribute	Statistic	Current State	Statistic Band	Overall Band
Wairoa at SH2	E. coli (Table 22)	95th Percentile (5 year)	2146	Poor	Poor

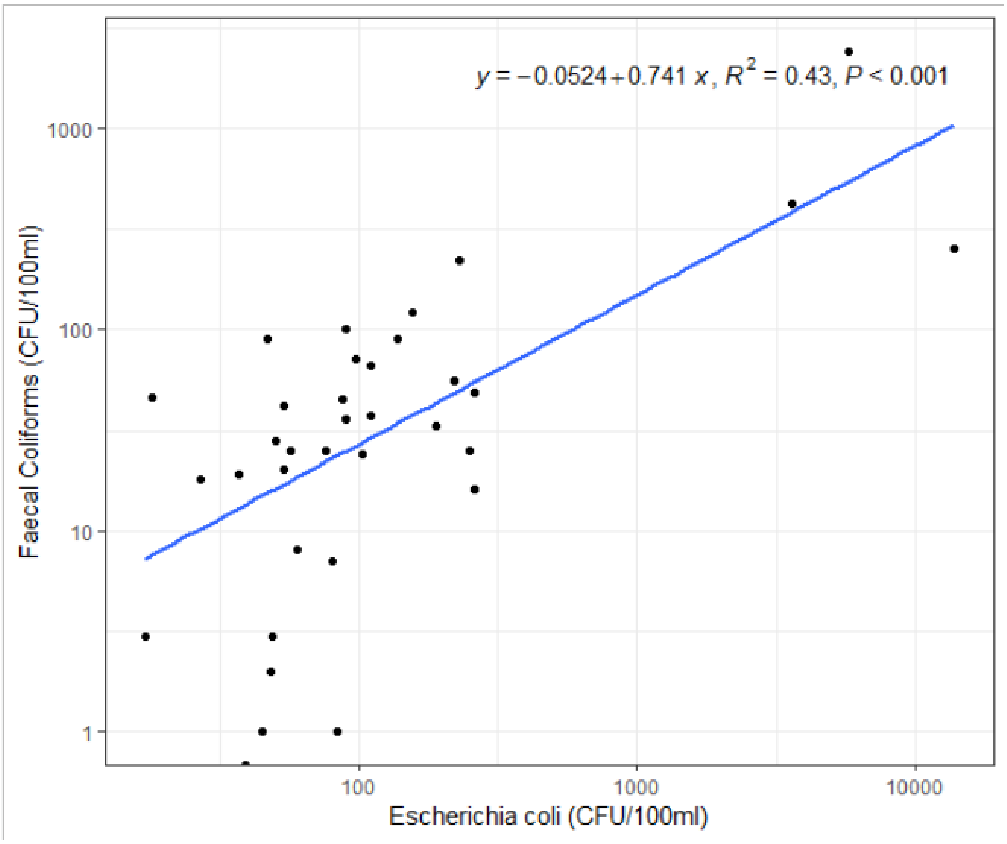

Figure 25 The relationship between Faecal Coliforms at the shellfish harvesting site (Y axis) and E. coli at the Wairoa River at SH2 bathing/NERMN site.

4.5.2 Concentration reduction

Figure 26 shows the cumulative distribution of Faecal Coliform concentrations at the Tilby Point shellfish harvesting site. This shows that the current distribution (red line) exceeds both the median threshold and the 90th percentile threshold. Simple analysis reveals that a 44% concentration reduction is required to meet the median threshold (14 CFU/100 ml) and a 64% reduction to meet the 90th percentile threshold (43 CFU/100 ml), all other factors being equal.

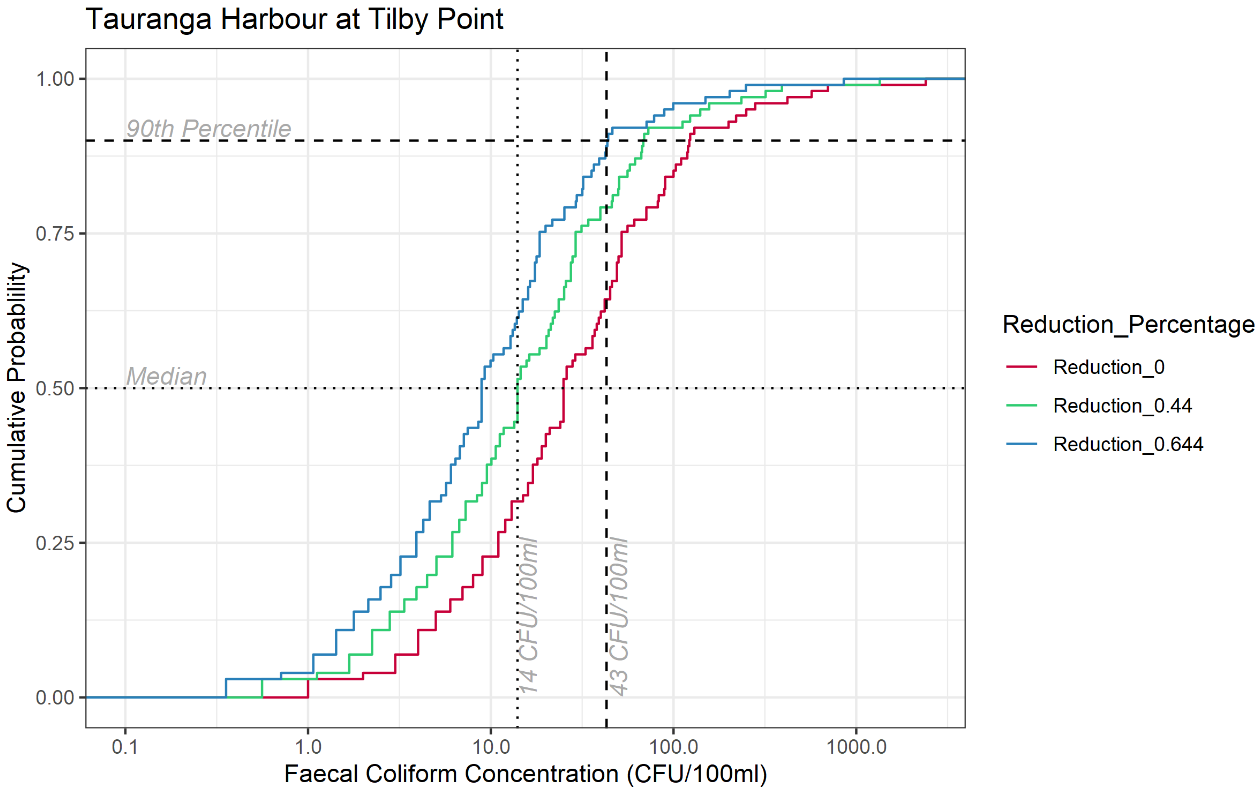

Figure 26 *Cumulative probability of Faecal Coliform concentrations at the Tauranga Harbour at Tilby Point shellfish harvesting site. The red line shows the current distribution (0% reduction), the green line shows a modified distribution that would meet the median value threshold (14 CFU/100 ml), and the blue line shows a modified distribution that would meet the 90th percentile threshold (43 CFU/100 ml). Corresponding percentage concentration reductions can be obtained from the legend.*

4.5.3 Load reduction

Hydrodynamic modelling results show that the Tilby Point recreational shellfish harvesting site is heavily dominated by the Waiau River (94%). There is also evidence from Figure 25 that suggests there is a moderate relationship between concentrations within the Wairoa River at SH2 NERMN/bathing site and faecal coliform concentrations at Tillby Point, which becomes stronger as riverine *E. coli* concentrations become elevated. With this in mind, it can be assumed load reductions to meet targets on the Wairoa River will have a positive impact on concentrations at the Tilby Point shellfish harvesting site.

As the Wairoa River at SH2 is both a NERMN (monthly water quality) and recreational bathing site (weekly during summer), LDC's have been provided for both Table 9 in Appendix 2A (Figure 27) and Table 22 in Appendix 2B of the NPS-FM (Figure 28), with corresponding load reductions displayed in Table 12 and Table 13.

The LDC for Table 9 of the NPS-FM shows that the 95th percentile numeric attribute is the only attribute to fail the swimmability criteria based on monthly NERMN data. This numeric attribute requires an overall load reduction of 11% to ensure this numeric attribute, and thus the overall state band, improves to a state that is deemed swimmable. Reductions can most effectively be made at the higher end of the FDC, i.e., in the 'Moist' and 'High' flow categories. All other numeric attributes have an overall state that is within the swimmability criteria, however exceedances occur for all numeric attributes for higher flow brackets. This indicates that this catchment mobilises a significant faecal load during higher flows which make the NERMN monitoring site unsuitable for swimming.

The bands for Table 22 of the NPS-FM are more stringent than Table 9 because it is targeted towards human health for primary contact and the thresholds are based on the MWQG (MfE, 2003). Data for this analysis has been limited to samples collected as part of the recreational bathing programme but are collected at the same physical location as those for the NERMN programme. The LDC relating to recreational bathing shows that the overall load reduction to improve the 95th percentile to meet or be better than the national bottom line (‘Poor’ band) is approximately 65%. Reductions can be targeted predominantly towards higher flows (Moist and High categories), but there are some elevated loads during dry conditions as well which indicates sources that are not mobilised by high flows (e.g., point sources).

In summary, a faecal contaminant load reduction of approximately 65% within the Wairoa catchment will ensure compliance with swimmability criteria for both Table 9 and Table 22 in the NPS-FM.

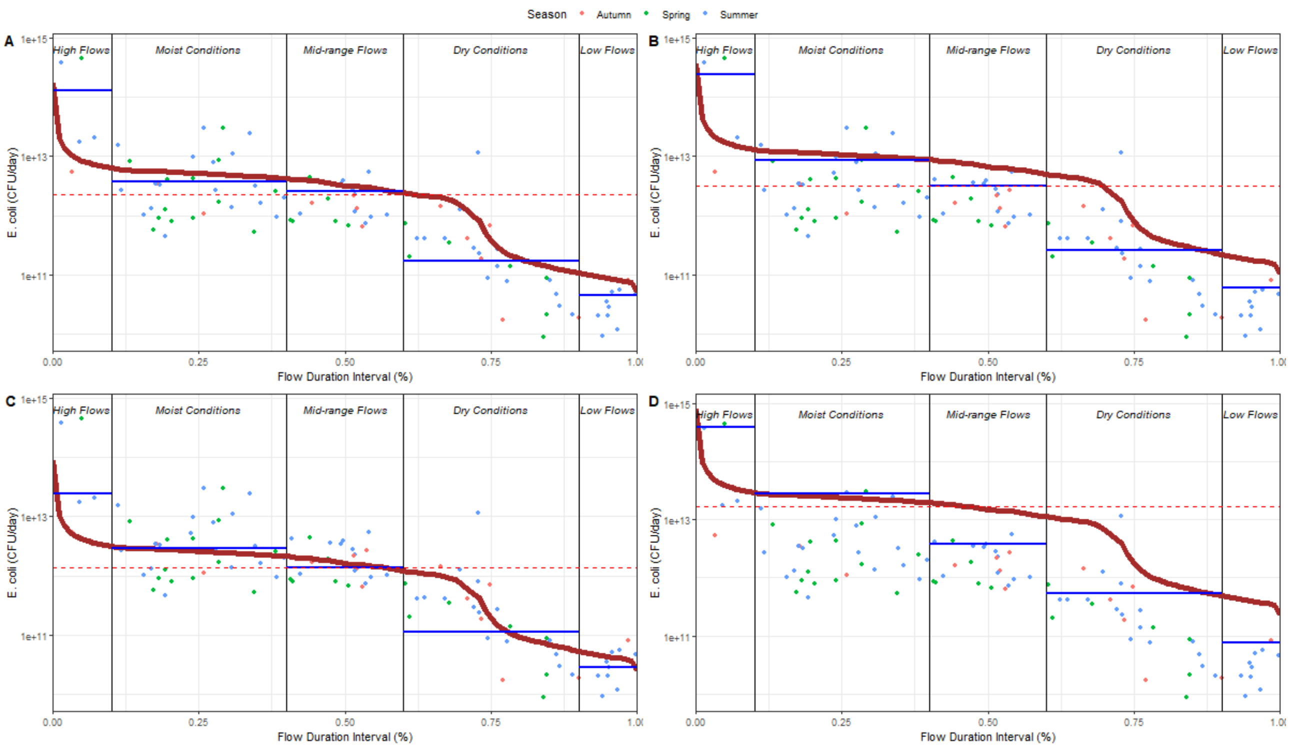

Figure 27 Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Wairoa River at SH2 NERMN site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown curve represents the swimmability (C/D) threshold for each numeric attribute.

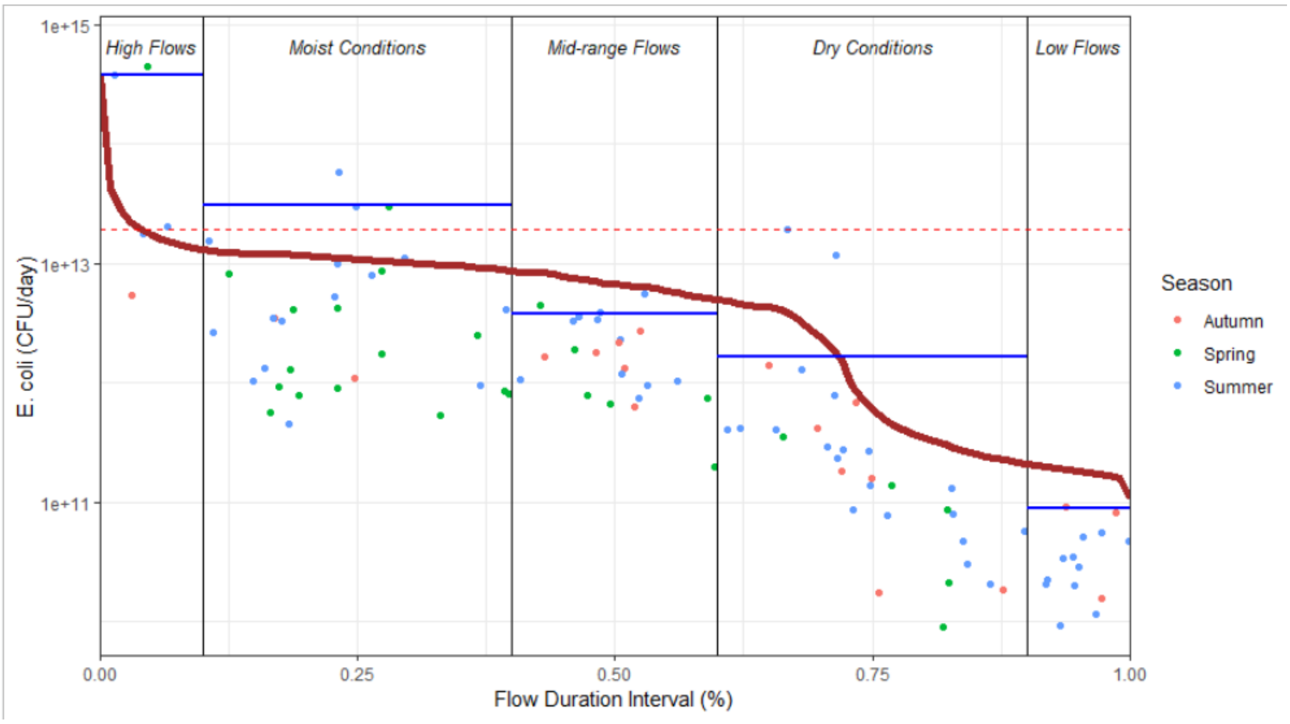

Figure 28 A load duration curve for the E. coli (primary contact) attribute (95th percentile) in Table 22 of the NPS-FM, for the Wairoa River at SH2 recreational bathing site. The figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown curve represents the swimmability threshold (540 CFU/100 ml).

Table 12 Output of the LDC analysis for the Wairoa at SH2 NERMN water quality site. The 'all' category is highlighted red and shows the overall load reduction required to meet the guideline threshold if flow-bins are ignored. Black text shows load reductions to meet the guideline threshold for each flow bin, which are independent of the 'all' calculation.

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Wairoa	Low	Exc260	0
Wairoa	Dry	Exc260	0
Wairoa	Mid-Range	Exc260	0
Wairoa	Moist	Exc260	0
Wairoa	High	Exc260	94
Wairoa	All	Exc260	0
Wairoa	Low	Exc540	0
Wairoa	Dry	Exc540	0
Wairoa	Mid-Range	Exc540	0
Wairoa	Moist	Exc540	0
Wairoa	High	Exc540	93
Wairoa	All	Exc540	0
Wairoa	Low	Median	0
Wairoa	Dry	Median	0

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Wairoa	Mid-Range	Median	0
Wairoa	Moist	Median	10
Wairoa	High	Median	83
Wairoa	All	Median	0
Wairoa	Low	Perc95	0
Wairoa	Dry	Perc95	0
Wairoa	Mid-Range	Perc95	0
Wairoa	Moist	Perc95	14
Wairoa	High	Perc95	90
Wairoa	All	Perc95	11

Table 13 Output of the LDC analysis for the Wairoa at SH2 NERMN recreational bathing water quality site.

Site	Percentile Category	Numeric Attribute	Load Reduction (%)
Wairoa	Low	Perc95	0
Wairoa	Dry	Perc95	64
Wairoa	Mid-Range	Perc95	0
Wairoa	Moist	Perc95	64
Wairoa	High	Perc95	96
Wairoa	All	Perc95	65

4.5.4 Knowledge to date

- The Tauranga Harbour at Tilby point shellfish harvesting site requires a concentration reduction of approximately 64% to meet both PMAS thresholds.
- The Wairoa River is the largest inflow to Tauranga Harbour, and hydrodynamic modelling suggests that this is by far the most dominant freshwater contributor (94% contribution) to the Tilby Point shellfish harvesting site.
- Paired samples collected on the same day show a moderately strong relationship between the Wairoa at SH2 bathing/NERMN site and the shellfish harvesting site, particularly for samples over 100 CFU/100 ml.
- Source tracing samples collected at Tauranga Harbour at Tilby Point shellfish harvesting site in December 2021 and January 2022 revealed positive markers for dog and avian sources (ESR, 2022). Flow conditions for the Wairoa River were low-moderate when these samples were collected, suggesting that sources are likely local. It's likely that local sources dominate when the flow in the Wairoa is low and catchment sources dominate when the flow is elevated.
- The Wairoa River at SH2 site requires a 11% load reduction to meet swimmability requirements (C grade or better) in Table 9 of Appendix 2A in the NPS-FM, and a 65% load reduction to improve the band beyond the NBL (95th percentile <= 540 CFU/100 ml) for Table 22 of Appendix 2B.
- Load reduction opportunities predominantly occur during 'Moist' to 'High flow' brackets. This suggests that sources generated by overland flow predominate in this catchment.

4.5.5 Knowledge gaps

- There is a lack of data to obtain a full understanding of how much influence the Wairoa River has upon concentrations at the shellfish monitoring site given estuarine currents. Further, the impact of other sources (local estuarine or septic) at the Tilby Point site are not well understood.
- There is no information regarding the relationship between shellfish water quality concentrations and flesh *E. coli* concentrations at the harvesting site.

4.5.6 Recommended future work

1. Additional faecal source tracing would be a useful addition to better understand the animal source at the shellfish site. This could be stratified by Wairoa flow conditions as higher flows are likely to reveal catchment derived sources, while elevated concentrations at lower flows are possibly more likely local sources.
2. Water quality vs. shellfish flesh concentrations could provide useful information on whether water concentrations are indicative of human health risk at this site.

Maketū Estuary

4.6 Maketū at Surf Club

Maketū Estuary has been the subject of a hydrodynamic modelling project carried out by DHI Water & Environment Ltd. The associated report, entitled 'Maketū Estuary – Numeric Modelling to Support Healthy Environments' (Chakravarthy et al., 2021a) was delivered to BOPRC in September 2021.

This section briefly summarises the main faecal bacteria results that were made in that report. Please refer to the report for more information.

4.6.1 Contaminant sources

The Maketū at Surf Club is located at the mouth of Maketū Estuary. The Kaituna River is the major freshwater input to the estuary, following its re-diversion that was completed in February 2020, and is likely to be the predominant source of faecal contamination. Other potential sources include oceanic inputs, inputs from fringing agricultural drains, local estuarine inputs, and inputs from the Maketū township (e.g., leaking septic, sewerage, or wastewater infrastructure).

Figure 29 The location of the Maketū at Surf Club shellfish harvesting site. The green line represents the Kaituna River which dominates the contribution of faecal contamination to this site.

4.6.2 Report summary

The Maketū Estuary hydrodynamic project modelled the response of Maketū Estuary to three catchment scenarios:

- **Baseline** represented the state of the Maketū Estuary in 2014 (selected as a representative year).
- **Scenario 1** represented a 'naturalised' state; and
- **Scenario 2** represented a likely future scenario where best practice, land retirement, land use change, and mitigations had been applied (eSource Scenario C + M1[1]).

Refer to Chakaravarthy et al. (2021a) for detailed information. However, notable findings from this report include:

- In all three scenarios, loads from the Kaituna River contributed more than 90% of both the enterococci and faecal coliform loads from the catchment to Maketū Estuary, over the period of a year.
- The predicted median faecal coliform levels met the median PMAS value of 14 CFU/100 ml in most of the estuary for all three Scenarios. In all three scenarios, the area near the south-eastern region of the estuary exceeded the 14 CFU faecal

[1] eWater SOURCE modelling platform was used to model in-stream water quality in the Kaituna River under different land and water use conditions (Legarth et al., 2020). The outputs from the modelling exercise were used as inputs by DHI for the Maketu and Waihi estuary modelling.

coliform/100 ml median threshold stated in the MWQG (MfE, 2003) for more than 40% of the annual period.

- Faecal coliform concentrations were better in summer than winter for most of the estuary during in Scenario 1 (naturalised state). Concentrations did not meet shellfish harvesting thresholds across most of the estuary during winter for all three Scenarios.
- Based on analysis at a 50th percentile level, a 39% reduction of baseline catchment loads is required for faecal coliform levels across the whole estuary to meet shellfish harvesting thresholds (identical to PMAS thresholds) for shellfish harvesting values.

Waihi Estuary

4.7 Waihī Estuary at Main Channel

Waihī Estuary was also the subject of a hydrodynamic modelling project carried out by DHI Water & Environment Ltd. The associated report, entitled 'Maketū Estuary – Numeric Modelling to Support Healthy Environments' (Chakravarthy et al., 2021b) was delivered to BOPRC in September 2021.

This section briefly summarises the main faecal bacteria results that were made in that report. Please refer to the report for more information.

4.7.1 Contaminant sources

The Waihī Estuary at Main Channel shellfish harvesting sites is located mid-channel, between Little Waihī and the Pukehina Township. There are three main freshwater inputs to the estuary: The Kaikokopu/Wharere Canal, The Pongakawa/Pukehina Canal, and a smaller canal to the west of the estuary. These inputs are likely to contribute most of the faecal bacteria load to the estuary, however other possible sources include local estuarine sources (e.g., birds etc.), fringing agricultural land, and inputs from fringing urban areas.

Ad-hoc on-site effluent testing (OSET) sampling has collected faecal source samples from four of the fringing drains that flow into Waihī Estuary. These were tested by ESR laboratories and returned negative results for Human markers(Cotterill & Scholes, 2021; ESR, 2021). Other markers were not tested as part of this programme.

Figure 30 The location of the Waihī Estuary at Main Channel shellfish harvesting site. The coloured lines at the bottom of the image represent major inflows to the estuary.

4.7.2 Report summary

The Waihī Estuary hydrodynamic project modelled the response of Waihi Estuary to three catchment scenarios:

- **Baseline** represented the state of the Maketū Estuary in 2014,
- **Scenario 1** represented a 'naturalised' state, and
- **Scenario 2** represented a likely future scenario where best practice, land retirement, land use change, and mitigations had been applied (eSource Scenario M1C[1]).

Refer to Chakaravarthy et al. (2021b) for detailed information. However, notable findings from this report include

- In all three scenarios, the Pongakawa River and Kaikokopu Stream contributed more than 70% of the faecal coliform loads from the catchment to Waihī Estuary.
- The predicted median faecal coliform levels within the estuary meet the shellfish harvesting median threshold value of 14 MPN per 100 ml set out in the MWQG (MfE, 2003) in both central and northern regions of the estuary for all three Scenarios.
- However, further results indicate that faecal coliform levels do not meet guideline values across most of the estuary during winter for all three Scenarios.
- Based on analysis at 50th percentile level, model results predict that a 51% reduction of baseline catchment loads is required for faecal coliform levels across the estuary to meet shellfish harvesting thresholds in the MWQG (MfE, 2003) (identical to PMAS thresholds).

Ōhiwa Harbour

4.8 Ōhiwa Harbour at Reserve (Boat Ramp)

4.8.1 Contaminant sources

The Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site is located on the northern side of Ōhiwa Harbour, close to the harbour entrance. The site is located on the opposite side of the harbour from the major inflow, the Nukuhou River, which flows to the ocean east of the shellfish site (Figure 31). There is one NERMN monitoring site located on the Nukuhou River entitled 'Nukuhou at Glenholme Road' which is also a rated hydrological site. This site has a current state of 'E' according to Table 9 in Appendix 2A of the NPS-FM (Table 14).

Figure 32 shows the relationship between elevated flow at the Nukuhou at Glenholme Road site and faecal coliform concentrations at the Ōhiwa Harbour at Reserve (Boat Ramp) site. The left panel shows faecal coliform concentrations over the past five bathing seasons, colour coded by flow percentile bracket on the Nukuhou River. If the river was directly influencing the shellfish harvesting site, samples collected during the 'High' bracket would be expected to have the highest concentrations at the shellfish site and samples collected during 'Low' flow brackets would be expected to have the lowest due to the volume of contaminated water leaving the Nukuhou catchment. This is not apparent in the left panel of Figure 32 which implies that sources impacting the shellfish harvesting site may be independent of direct input from the Nukuhou River. This is based, however, on the assumption that faecal loads increase during higher flows.

The right-hand panel of Figure 32 shows how Faecal Coliform concentrations at the shellfish site are related to the flow percentile from the Nukuhou River for each sample taken on the same day (black dots) or the flow percentile from the previous day (red dots). The reason for showing the previous day percentiles is to help test whether there may be a time lag as water and faecal contamination is flushed from the Nukuhou catchment. If this were the case, higher concentrations would be expected on the left side of the graph and lower concentrations on the right are expected; however, there is no such apparent pattern in the right-hand panel of Figure 32. Again, this suggests that there is no direct relationship between high flows on the Nukuhou River and concentrations at the shellfish harvesting site.

Other possible sources of faecal contamination at the shellfish harvesting site include local estuarine sources, oceanic sources, and potential local septic inputs. A small investigation was carried out to investigate local sources in September 2021. This involved sampling at four sites: Ōhiwa Harbour at Reserve (Boat Ramp); 300m east of the boat ramp site, 300 m west of the boat ramp site, and the Port Ōhope Wharf (approximately 2 km west of the boat ramp). Twelve samples were collected from each site throughout a three-week period. All sites were located approximately 2m from the shore, with the exception of the Port Ōhope Wharf site which allowed for sampling approximately 8 m-15 m from shore depending on the tide.

Results showed that all sites were elevated to some degree, although the site with the most consistently low concentrations was Port Ōhope Wharf (Figure 33). As the site name suggests, this site is located at the end of a wharf that extends into the main channel of Ōhiwa Harbour, allowing the samples to be collected from deeper water than the other shore-based sites. This raises the possibility of fine sediment located around the shoreline harbouring faecal contaminant, although this is just a theory at this stage. All sites had exceeded the 43 CFU/100 ml threshold for 8% of the samples which meets the 90th percentile guideline, however the Ohiwa Harbour 300m West of Reserve (Boat Ramp) site had a median of 18 CFU/100 ml which exceeded the median guide of 14 CFU/100 ml (Table 15).

This investigation suggests that the contamination seen at the Ōhiwa Harbour at Reserve (Boat Ramp) site is not confined to the immediate area and occurs for at least 300 m either side of the boat ramp and possibly up to 2 km to the west at the Port Ōhope Wharf. Sediment-bound concentrations were not analysed, however the improvement of results with deeper water may suggest that contamination is sediment bound, opening up potential scenarios of delayed mobilisation and intra-estuary transport with sediment exported from the Nukuhou Catchment, as well as other fringing catchments.

Figure 31 *The location of the Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site. The pink line represents the flow path of the Nukuhou River at low tide.*

Table 14 *Attribute statistics and grades for the Nukuhou at Glenholme Road NERMN water quality site, according to Table 9 in Appendix 2A of the NPS-FM.*

Site	Attribute	Statistic	Current State	Statistic Band	Overall Band
Nukuhou at Glenholme Road	E. coli (Table 9)	Exceedance 260 (%)	59	E	E
		Exceedance 540 (%)	35	E	
		Median (5 year)	315	E	
		95^{th} Percentile (5 year)	3805	D	

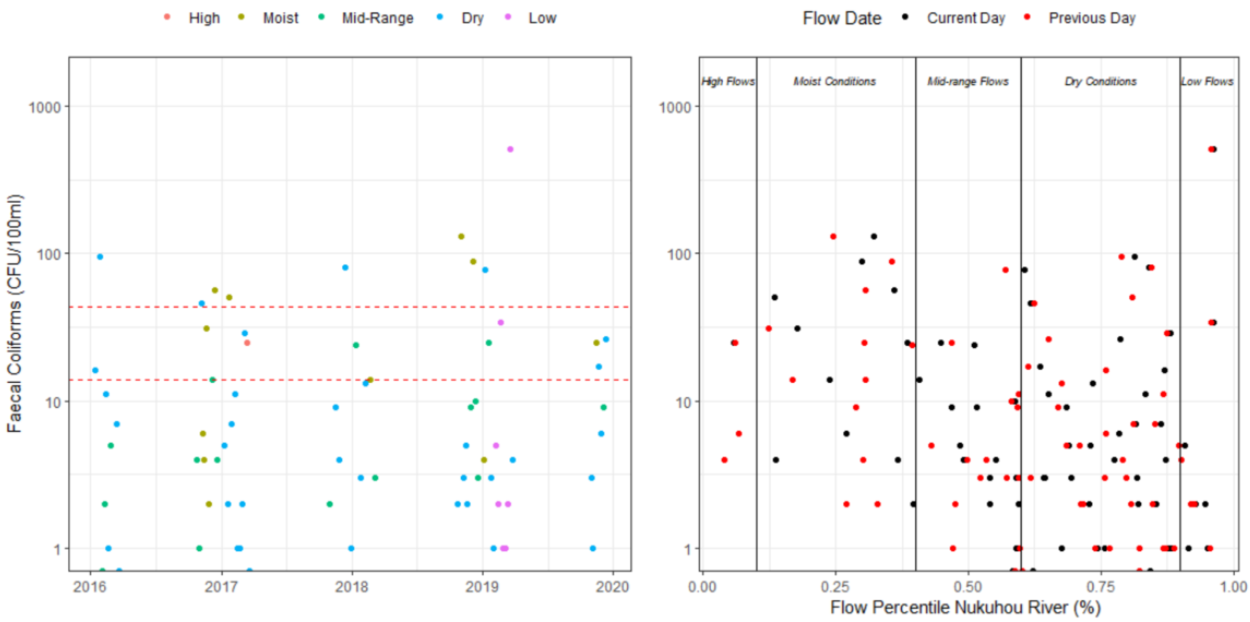

Figure 32 *The relationship between elevated flows on the Nukuhou River and Faecal Coliform concentrations at the Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site. The left panel shows Faecal Coliform concentrations by bathing season, colour coded by the flow percentile bracket on the Nukuhou. The horizontal dashed lines represent the 14 CFU/100 ml (median) and 43 CFU/100 ml (90th percentile) shellfish harvesting limits. The right panel shows the relationship between Faecal Coliform concentration at the shellfish site and the flow percentile on the Nukuhou River. Points are colour coded black to show the flow percentile on the day of sampling, and red to show the flow percentile from the previous day (i.e., delayed delivery).*

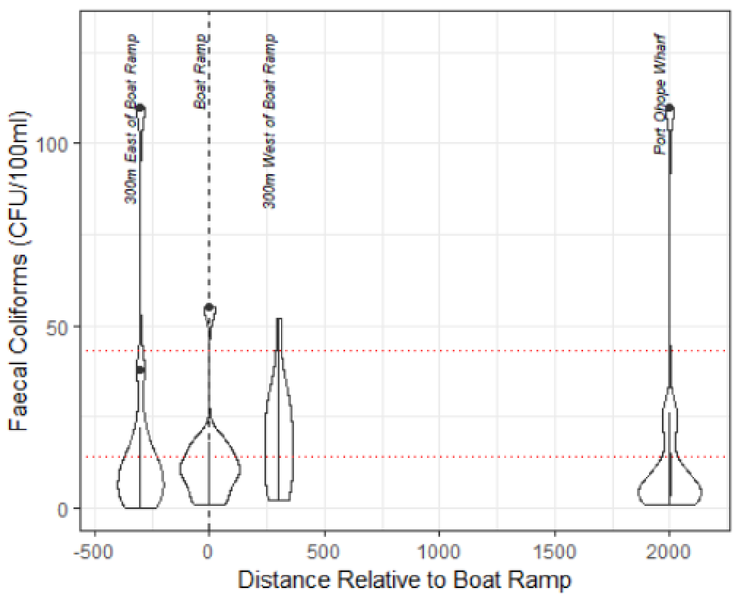

Figure 33 *Faecal Coliform concentrations at four sites that were part of an investigation to determine the spatial extent of contamination at the shellfish harvesting site. The vertical dashed line represents the location of the shellfish harvesting site, and the x axis represents the distance (in metres) east (negative) or west (positive) from the shellfish harvesting site. Data are presented as a 'violin' plot, where the width of the 'violin' represents the density of values. Horizontal red dashed lines show the 14 CFU/100 ml median PMAS threshold and the 43 CFU/100ml 90th percentile threshold.*

Table 15 Faecal Coliform results for the local source investigation.

Site	Median concentration	Percent > 43 CFU/100 ml (%)	n
Ohiwa Harbour 300 m East of Reserve (Boat Ramp)	11	8	12
Ohiwa Harbour 300 m West of Reserve (Boat Ramp)	17.5	8	12
Ohiwa Harbour at Port Ohope Wharf	5.5	8	12
Ohiwa Harbour at Reserve (Boat Ramp)	10.5	8	12

4.8.2 Concentration reduction

Figure 34 shows a cumulative distribution of faecal coliform concentrations at the Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site. This figure shows that the current concentration distribution meets the 14 CFU/100 ml threshold (median value) but slightly exceeds the 43 CFU/100 ml (90^{th} percentile) threshold. Assuming the distribution remains consistent as concentrations reduce (i.e., the shape remains the same), this analysis shows that a concentration reduction of 23% is required to shift the distribution to a state that would meet the 43 CFU/100 ml threshold (blue line).

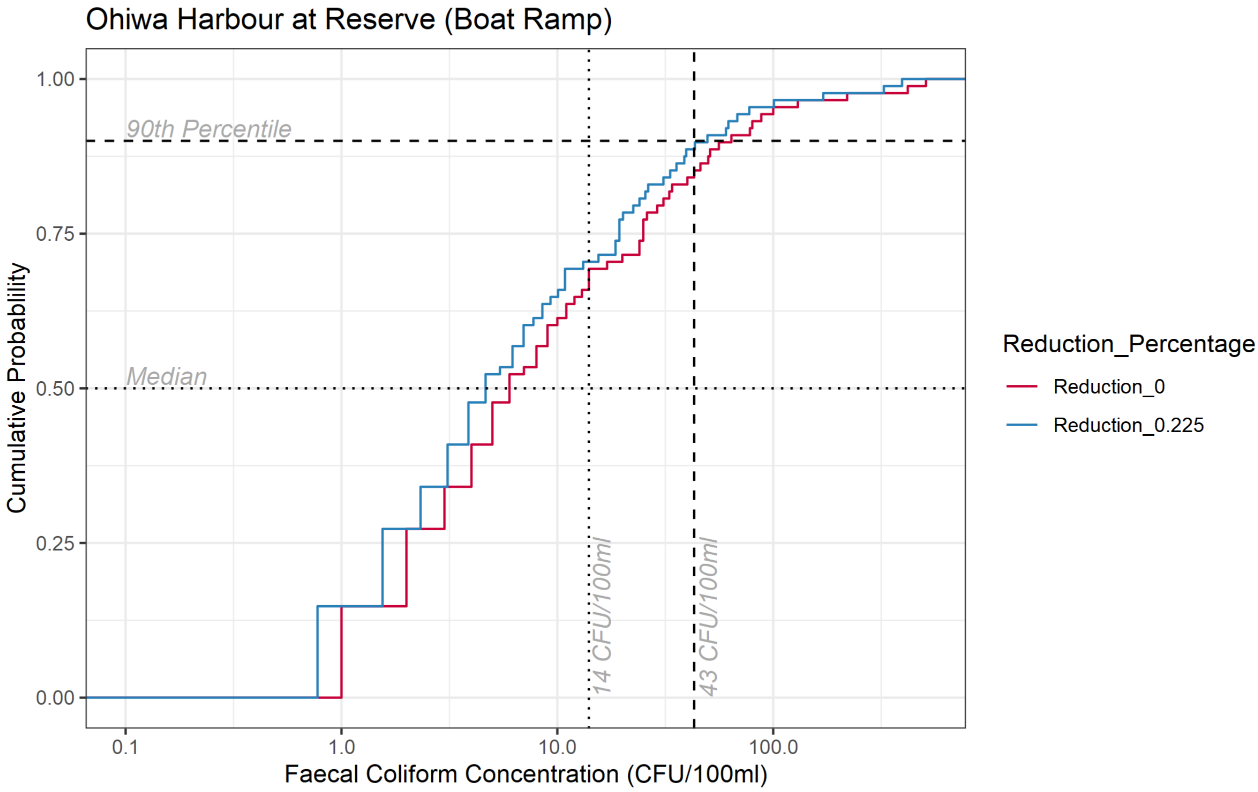

Figure 34 Cumulative probability of Faecal Coliform concentrations at the Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site. The red line shows the current distribution (0% reduction), and the blue line shows a modified distribution that would meet the 90^{th} percentile threshold (43 CFU/100 ml). Corresponding percentage concentration reductions can be obtained from the legend.

4.8.3 Load reduction

The degree of influence that the major inflow to Ōhiwa Harbour (the Nukuhou River) has on the shellfish harvesting site is unknown. Evidence in Figure 32 suggests that the influence may be minor, at least at a short timescale (1-2 days), however a hydrodynamic model would be needed to better understand and estimate how contaminants are transported throughout the estuary, and the associated lag time between load delivery and elevated contamination at the shellfish site.

Regardless of just how much influence the Nukuhou River has on the shellfish harvesting site, a reduction in *E. coli* loading in the Nukuhou River to meet swimmability thresholds for Table 9 in Appendix 2A of the NPS-FM, is likely to be positive for concentrations at the Ōhiwa shellfish harvesting site. LDC analysis (Figure 35 and Table 16) shows that improvement is needed across all four attributes to meet swimmability criteria, with *E. coli* load reductions ranging from 21% (percent exceedance of 540 CFU/100 ml) to 69% (95th percentile). Load reductions can be made for all flows, however the percentage required is typically larger for higher flow bins. Overall, a 69% load reduction is needed to meet all the swimmability criteria (see largest of the red rows indicated in Table 16).

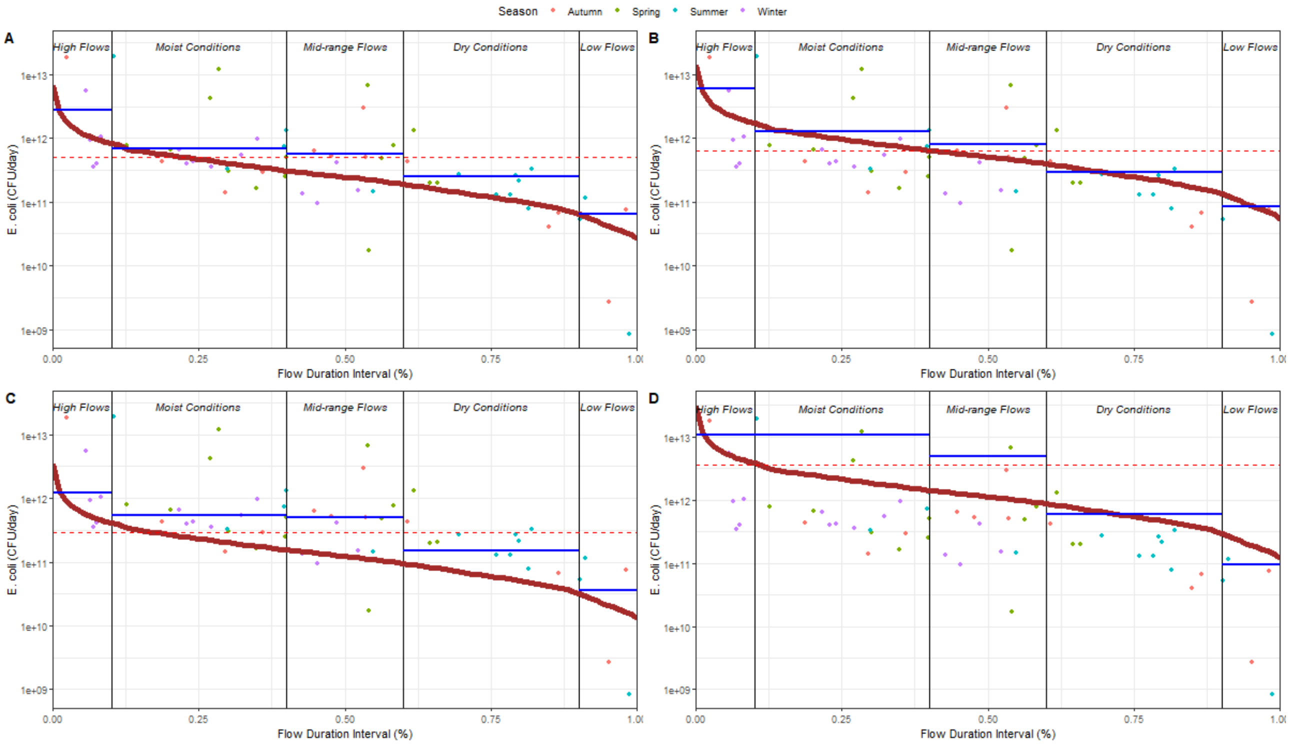

Figure 35 Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Nukuhou at Glenholme Road NERMN site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown curve represents the swimmability (C/D) threshold for each numeric attribute.

Table 16 Output of the LDC analysis for the Nukuhou at Glenholme Road NERMN water quality site.

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Nukuhou	Low	Exc260	34
Nukuhou	Dry	Exc260	52
Nukuhou	Mid-Range	Exc260	57
Nukuhou	Moist	Exc260	32
Nukuhou	High	Exc260	56
Nukuhou	All	Exc260	52
Nukuhou	Low	Exc540	0
Nukuhou	Dry	Exc540	15
Nukuhou	Mid-Range	Exc540	36
Nukuhou	Moist	Exc540	23
Nukuhou	High	Exc540	59
Nukuhou	All	Exc540	21
Nukuhou	Low	Median	41
Nukuhou	Dry	Median	61
Nukuhou	Mid-Range	Median	76
Nukuhou	Moist	Median	57
Nukuhou	High	Median	50
Nukuhou	All	Median	59
Nukuhou	Low	Perc95	0
Nukuhou	Dry	Perc95	8
Nukuhou	Mid-Range	Perc95	77
Nukuhou	Moist	Perc95	80
Nukuhou	High	Perc95	49
Nukuhou	All	Perc95	69

4.8.4 Knowledge to date

- Concentrations of faecal coliforms at the Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site require a concentration reduction of 23% to meet both PMAS thresholds.
- There does not appear to be a relationship between elevated flow on the Nukuhou River and faecal coliform concentrations at the Ōhiwa Harbour site. This finding is consistent for flow on the day of sampling and flow from the previous day.
- A short investigation shows that minor to moderate contamination is consistent along the northern inner fringe of the harbour, and Faecal Coliform concentrations at investigation sites are similar to that at the shellfish harvesting site. Concentrations seemed to be lower at the Port Ōhope Wharf where samples were able to be collected from deeper water. It is possible that resuspension of shoreline sediments may elevate faecal coliform concentrations, however, concentration reductions could also be due to increased distance from the original shellfish harvesting site.
- The Nukuhou River has excessive concentrations of *E. coli* and is rated an ‘E’ according to Table 9 in Appendix 2A of the NPS-FM.

- LDC analysis suggests that E. coli loads in the Nukuhou River would have to reduce by 69% to improve all four numeric attributes to a swimmable state (i.e., a ‘C’ band or better).

4.8.5 Knowledge gaps

- There is no information describing how faecal contamination loads from the Nukuhou River are diluted and transported within Ōhiwa Harbour. A hydrodynamic model is possibly the easiest method to understand this, although dye-dilution studies could also provide some insight.
- There are no *E. coli* results from the centre of the harbour where most shellfish are harvested. Without sampling, a hydrodynamic model is the only way to estimate whether shellfish waters exceed the PMAS.
- The brief investigation described above raised questions around the interaction of deposited sediment on the harbour fringe and faecal coliform concentrations. However, there is no empirical evidence that confirms sediment deposits as sources of contamination.
- There is currently no information on the faecal source of elevated concentrations at the shellfish harvesting site.
- There is no information linking elevated concentrations of faecal coliforms in the water column to elevated flesh concentrations. This is important because the site only exceeds the 43 CFU/100 ml threshold and not the 14 CFU/100 ml median threshold, and flesh may remain relatively safe to eat.

4.8.6 Recommended future work

1 Investigate faecal coliforms in the water column and concentrations in shellfish flesh at numerous harvesting sites in the harbour. This should include sites at shellfish beds in the centre of the harbour.

2 Faecal coliform samples should be prioritised for FST if concentrations are high enough to provide a reliable result. This may provide information on whether the source is ruminant, therefore likely to be coming from one of the rural catchments, or human and therefore likely to be coming from urban areas.

3 A hydrodynamic model could be useful to better understand how contamination is transported around the harbour and which areas are most likely to be affected. This could also provide more certainty around the source of contamination.

Waiōtahe Estuary

4.9 Waiōtahe at Estuary

4.9.1 Contaminant sources

The Waiōtahe at Estuary shellfish harvesting site is located at the mouth of the Waiōtahe Estuary, which is dominated by the Waiōtahe River inflow (Figure 36). Other inflows include numerous side tributaries and drains from adjacent landuse, however contaminant inputs from these areas are likely to be minimal compared to the mainstem Waiōtahe River.

The Waiōtahe Catchment spans from areas of native forest in the Te Urewera Range, through areas of steep and rolling hill country, to intensively farmed alluvial plains in the lower catchment (Banks, 2011). The lower catchment is subject to regular flooding, requiring a comprehensive drainage scheme with numerous channels and pumpstations to ensure farm productivity. This area contains several intensive dairy farms and is thought to be a significant source of faecal contamination to the estuary.

The Waiōtahe River contains one NERMN river water quality site, Waiōtahe at Toone Road, which is currently graded a ‘B’ band according to Table 9 in Appendix 2A of the NPS-FM (MfE, 2020). However, this site is located upstream of the drainage network, and is therefore not likely to be representative of the level of contamination in the lower part of the catchment.

The Waiōtahe Catchment has also been subject to a comprehensive water quality investigation that began in 2017 and covered 27 monitoring sites throughout the catchment (Dada, 2021). Each site was sampled for *E. coli*, among other things, and generally showed a pattern of good water quality in the upper catchment degrading to poorer water quality in the lower catchment (Dada, 2021). Dada (2021) also found that agricultural drains in the catchment tended to have increased contaminant concentrations after rainfall, and that longer dry periods showed greatly reduced concentrations. However, *E. coli* concentrations were seen to persist for a long time after rainfall events, suggesting that wastewater discharges from farms, direct deposition from animals, or naturalised *E. coli* growth were possibly maintaining concentrations. Seasonal observations saw the highest levels of *E. coli* occurring during autumn months, with a decrease in winter months as temperatures drop. Wet spring months saw the highest *E. coli* concentrations in the lower catchment in agricultural drains.

Dada (2021) also employed a simple mixing model to provide insights into the relationship between water and sediment *E. coli* concentrations. This suggested that there may be a net transfer of *E. coli* from water to sediments under spring conditions when *E. coli* concentrations in the water column exceeded that in the sediment due to colder winter temperatures. When *E. coli* bound to sediment were exposed to warmer temperatures from summer to autumn, naturalised populations were hypothesised to reproduce rapidly and a transfer back from the sediment to the water. However, Dada (2021) also noted that this process was likely to be complicated by increased UV-light occurring during summer months which is known to cause *E. coli* mortality therefore reducing water column concentrations.

Figure 36 The location of the Waiōtahe at Estuary shellfish harvesting site. The green line represents the flow path of the Waiōtahe River at low tide.

Table 17 Attribute statistics and grades for the Waiōtahe at Toone Road NERMN water quality site, according to Table 9 in Appendix 2A of the NPS-FM.

Site	Attribute	Statistic	Current State	Statistic Band	Overall Band
Waiōtahe at Toone Rd	E. coli (Table 9)	Exceedance 260 (%)	16	A	B
		Exceedance 540 (%)	9	B	
		Median (5 year)	60	A	
		95^{th} Percentile (5 year)	938	B	

4.9.2 Concentration reduction

Figure 37 shows a cumulative distribution of Faecal Coliform concentrations at the Waiōtahe at Estuary shellfish harvesting site. This figure shows that the current distribution exceeds both the 14 CFU/100 ml (median) and 43 CFU/100 ml (90^{th} percentile) thresholds. Analysis shows that a concentration reduction of 62% is required to meet the median threshold (green line), and 84% to meet the 90^{th} percentile threshold (blue line), assuming the modified distribution maintains the same shape as the current distribution.

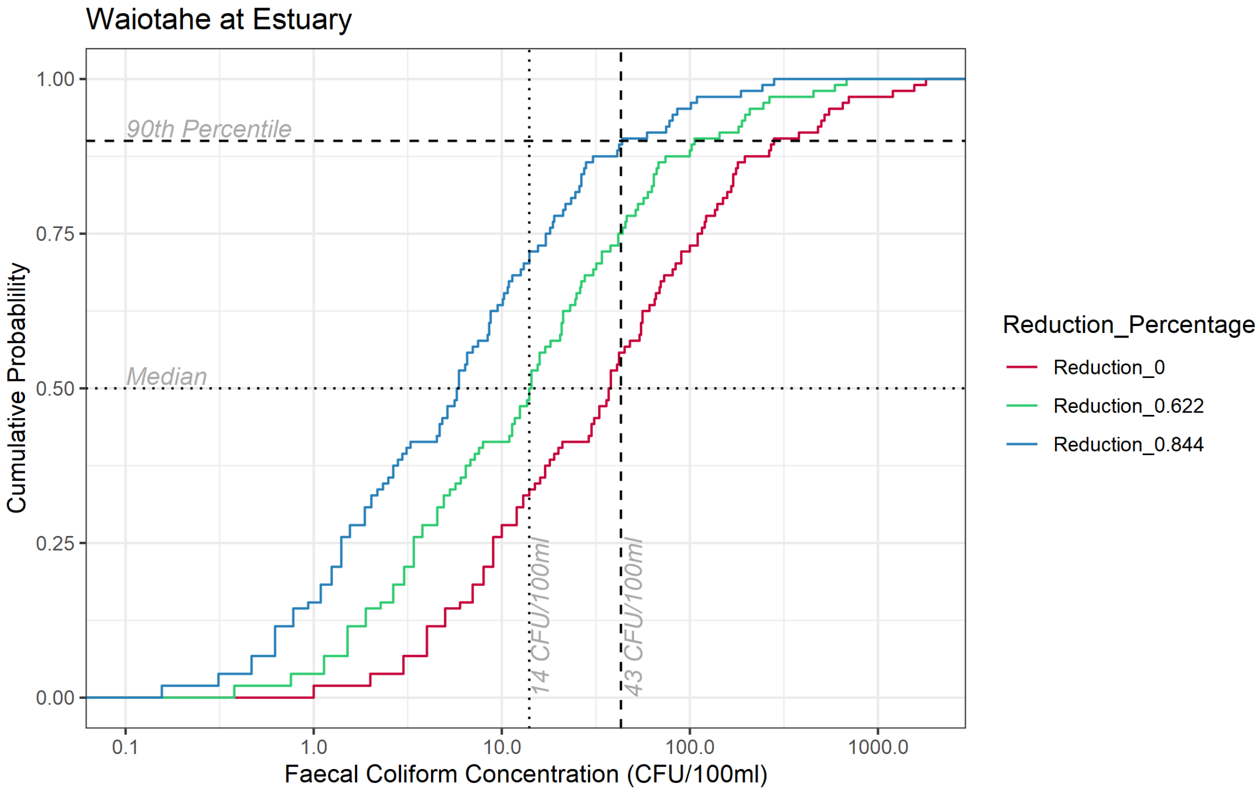

Figure 37 Cumulative probability of Faecal Coliform concentrations at the Waiōtahe at Estuary shellfish harvesting site. The red line shows the current distribution (0% reduction), the green line shows a modified distribution that would meet the median value threshold (14 CFU/100 ml), and the blue line shows a modified distribution that would meet the 90th percentile threshold (43 CFU/100 ml). Corresponding percentage concentration reductions can be obtained from the legend.

4.9.3 Load reduction

The Waiōtahe Catchment has been intensively monitored since 2017 which provides useful information for determining 'target loads' for meeting NPS-FM concentration thresholds. However, this catchment is affected by tidal displacement in the lower reaches, making it impractical to collect discharge data at many lowland water quality sites. This means that *E. coli* loads could only be calculated in the upper catchment, above the lowland drainage system that is thought to contribute disproportionately more to catchment *E. coli* loads. In response to this problem an attempt was made to generate synthetic estimates of flow at lower catchment sites, as described in the next sub-section.

4.9.4 Developing synthetic flow estimates for the lower catchment

This analysis attempts to improve catchment load estimates by developing synthetic flow records for flow-absent water quality sites in the lower catchment.

Sites of importance to this analysis are (Figure 38):

- **Waiōtahe River u/s Verrall Road** - the most downstream water quality monitoring site on the main Waiōtahe River
- **Verrall and Wilsons Drains**, two significant drainage systems in the lower catchment that discharge into the Waiōtahe River downstream of Verrall Road.

- **Waiōtahe River at Waiōtahe Hall** – a mainstem site that is located upstream of major lowland drainage networks. This site was used to represent background water quality conditions upstream of the lowland drainage network.
- **Rau Road Drain at Rau Road** – a drainage system site located in the mid-catchment. This site has monthly spot flow data which was used to develop a relationship with the closest hydrological site (Nukuhou at Glenholme Road) to represent flow in lowland drainage sites.
- **Waiōtahe Valley at 1263 Waiōtahe Road** – a mainstream site located in the upper catchment. This site has monthly spot flow data which was used to develop a relationship with the closest hydrological site to represent mainstem sites.
- **Waiōtahe River at Terminal Reach -** the most downstream reach of the Waiōtahe River. This is a hypothetical site (i.e., it was not physically monitored) that was used to calculate catchment export of faecal contamination.

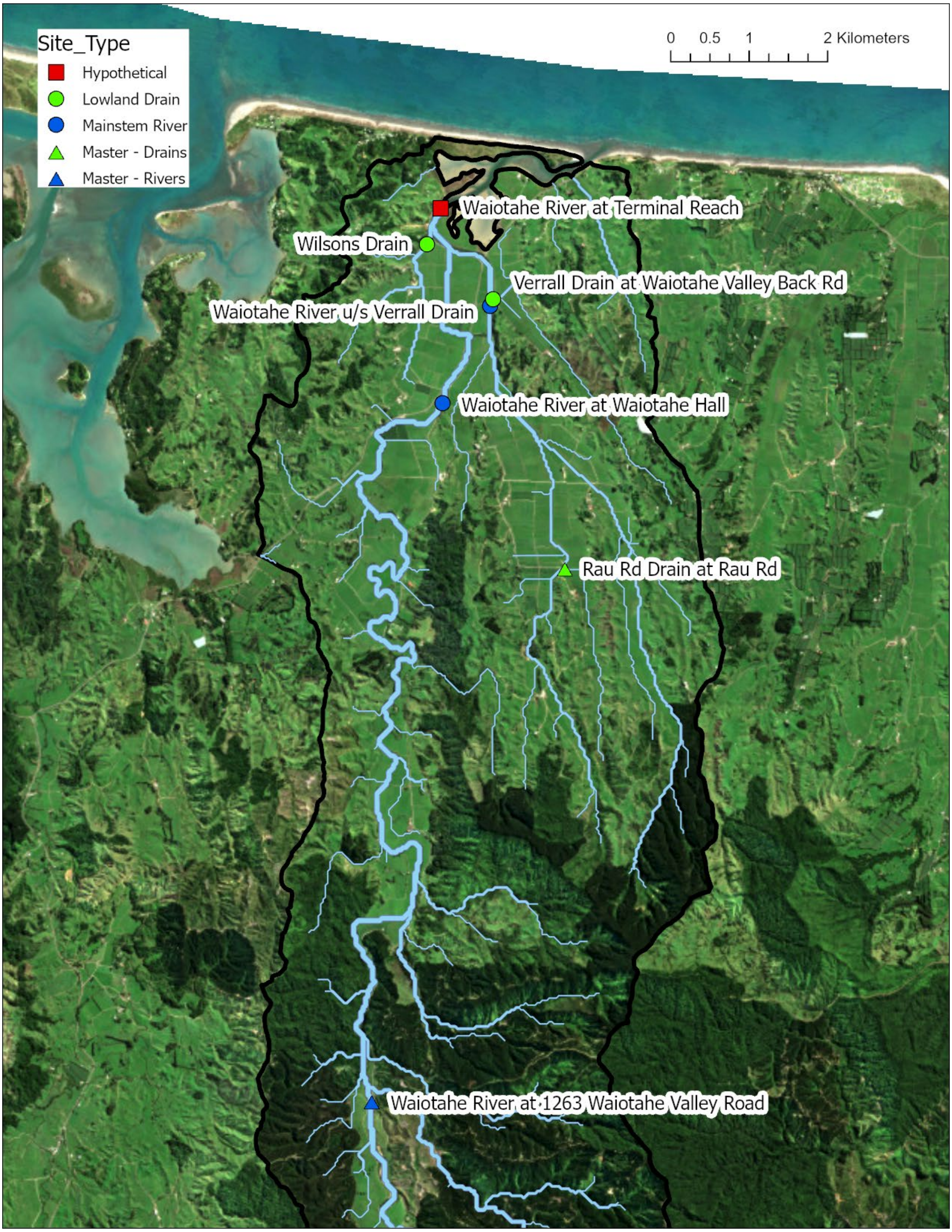

Figure 38 *Sites of interest within the Waiōtahe Catchment. Sites are categorised based on their 'type', i.e., master flow sites (triangles), water quality sites (circles), or hypothetical sites (squares). Colours represent mainstem (blue), or drainage network (green) sites, with the exception of the hypothetical site which is coloured red.*

Flow records for flow-absent lower catchment water quality sites were developed using the following steps:

1 **A continuous (synthetic) flow record was developed for sites in the upper Waiōtahe Catchment where spot flow data is available** – The Waiōtahe Catchment lacks a hydrological site with a continuous flow record, therefore the continuous flow record at the Nukuhou at Glenholme Road hydrological site was used (Figure 39) as the proxy for flow in the Waiōtahe Catchment. The Nukuhou site is located in a neighbouring catchment and has similar geological characteristics to the Waiōtahe Catchment.

   Relationships were developed between mean hourly flow values from Nukuhou at Glenholme Road and two spot gauging sites in the upper Waiōtahe Catchment, Waiōtahe River at 1263 Waiōtahe Road (Figure 40), and Rau Road Drain at Rau Road (Figure 41). These sites were selected to represent the two types of flow environments present in the lower Waiōtahe Catchment, i.e., mainstem river and lowland drain environments. R squared values were 0.62 for the Waiōtahe Road site and 0.68 for the Rau Road Drain site, implying a reasonable relationship with moderate levels of unexplained variation.

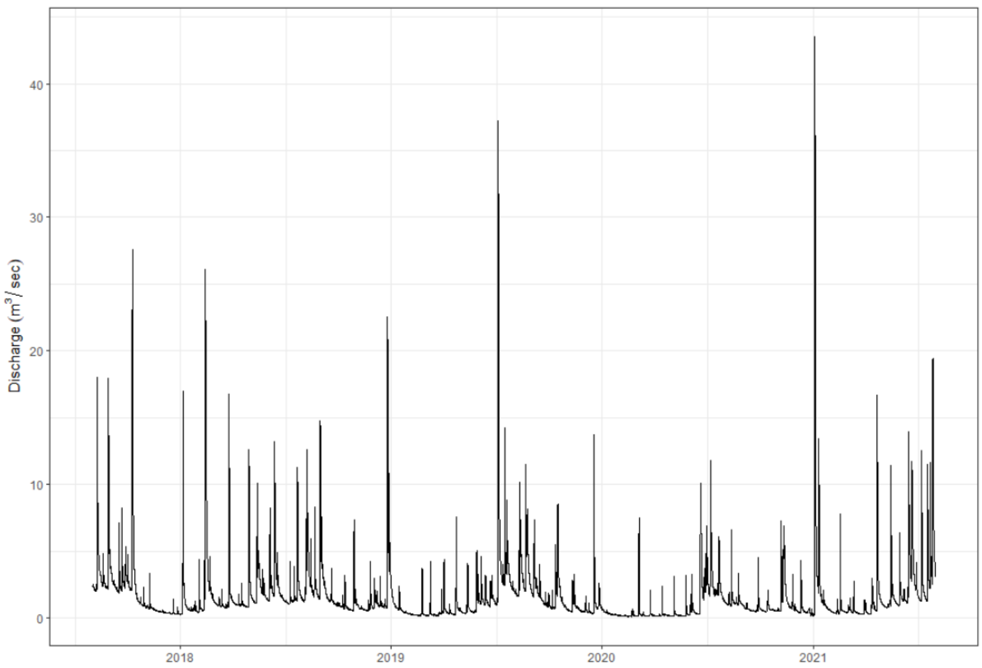

Figure 39 Hydrograph for the Nukuhou at Glenholme Road hydrological site.

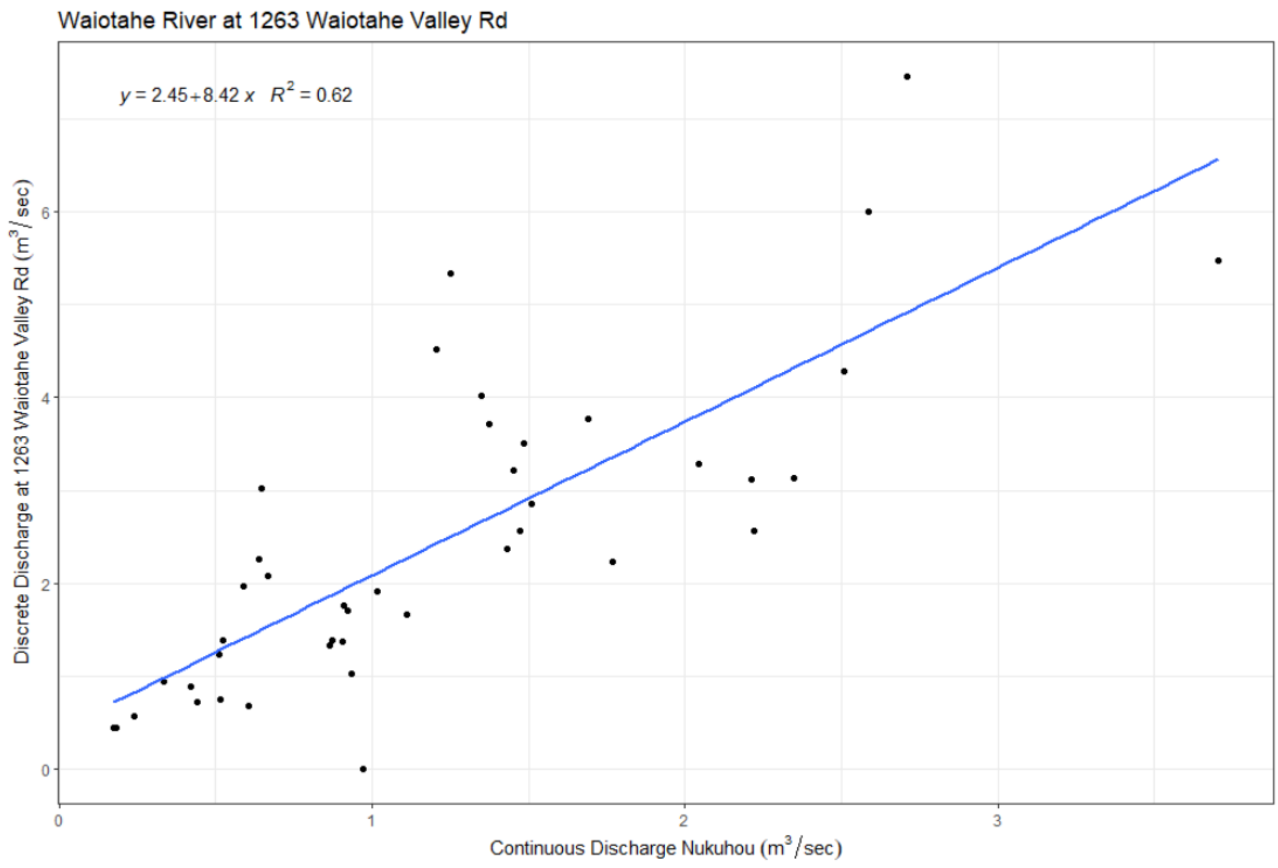

Figure 40 *Relationship between mean hourly discharge at the Nukuhou at Glenholme Road hydrological site, and spot gauging at the Waiotahe River at 1263 site.*

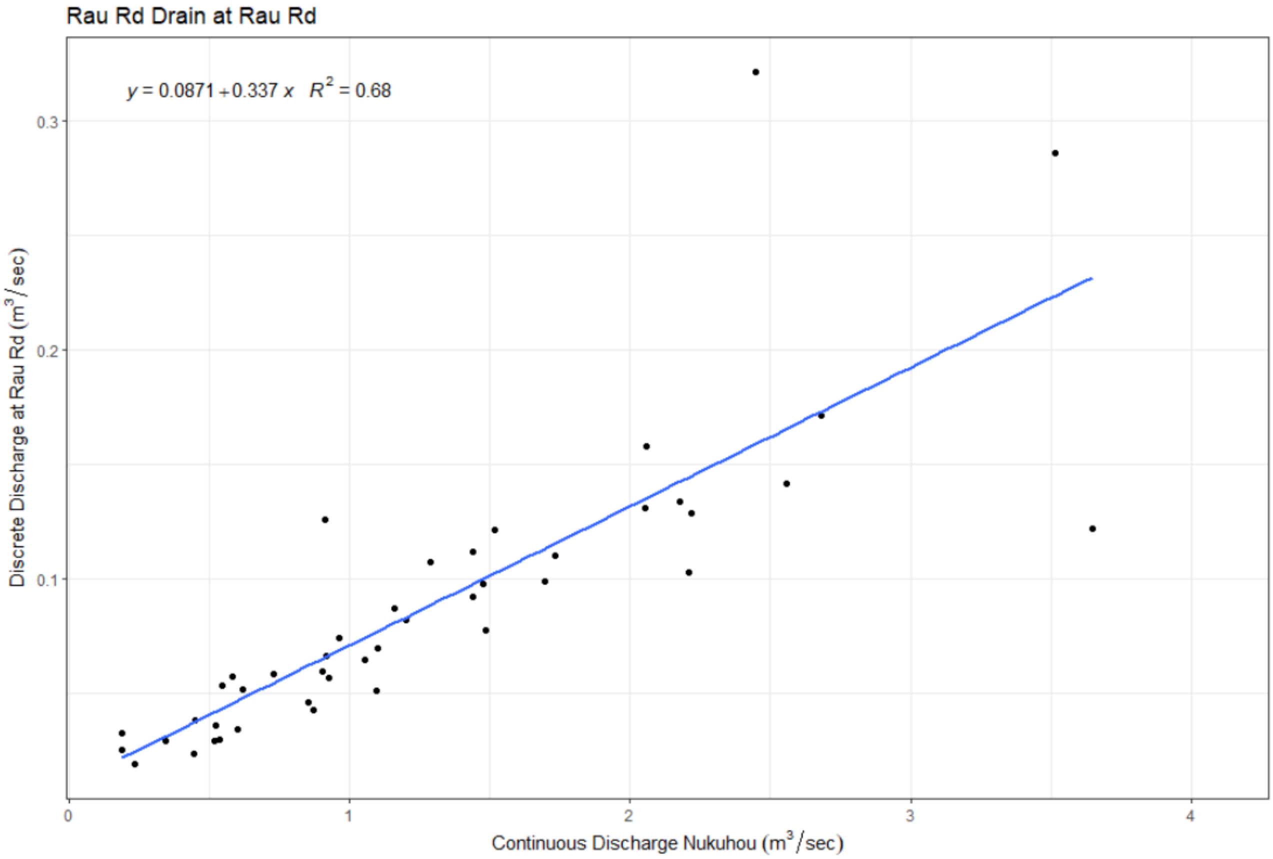

Figure 41 Relationship between mean hourly discharge at the Nukuhou at Glenholme Road hydrological site, and spot gauging at the Rau Road Drain at Rau Road site.

2 **Random forest FDC models were used to compare the FDC at reaches of flow-absent sites in the lower catchment to newly established synthetic flow sites in the upper catchment (Figure 42)** – FDC models were obtained from Doug Booker at NIWA, and an explanation of the methodology used to develop these can be found in Booker and Woods (2014). Flow absent sites in the lower catchment include Waiōtahe u/s Verall Road (mainstem site), Waiōtahe at Waiōtahe Hall (mainstem site), Verrall Drain (drain site), and Wilsons Drain (drain site). A minor error in the REC dataset placed Waiōtahe u/s Verall Road and Waiōtahe at Waiōtahe Hall on the same REC reach. Although there are inflows between the sites, the difference was not deemed to be important given the uncertainties in this method, therefore the same FDC comparison was used for both sites (labelled as Waiōtahe u/s Verrall Drain in Figure 42 and Figure 43). Finally, a fourth site was added, 'Waiōtahe at Terminal Reach'. This site is not an established water quality site, but instead was used to obtain the flow required to determine if cumulative *E. coli* loads at the reach immediately above the Waiōtahe Estuary breaches NPS-FM thresholds.

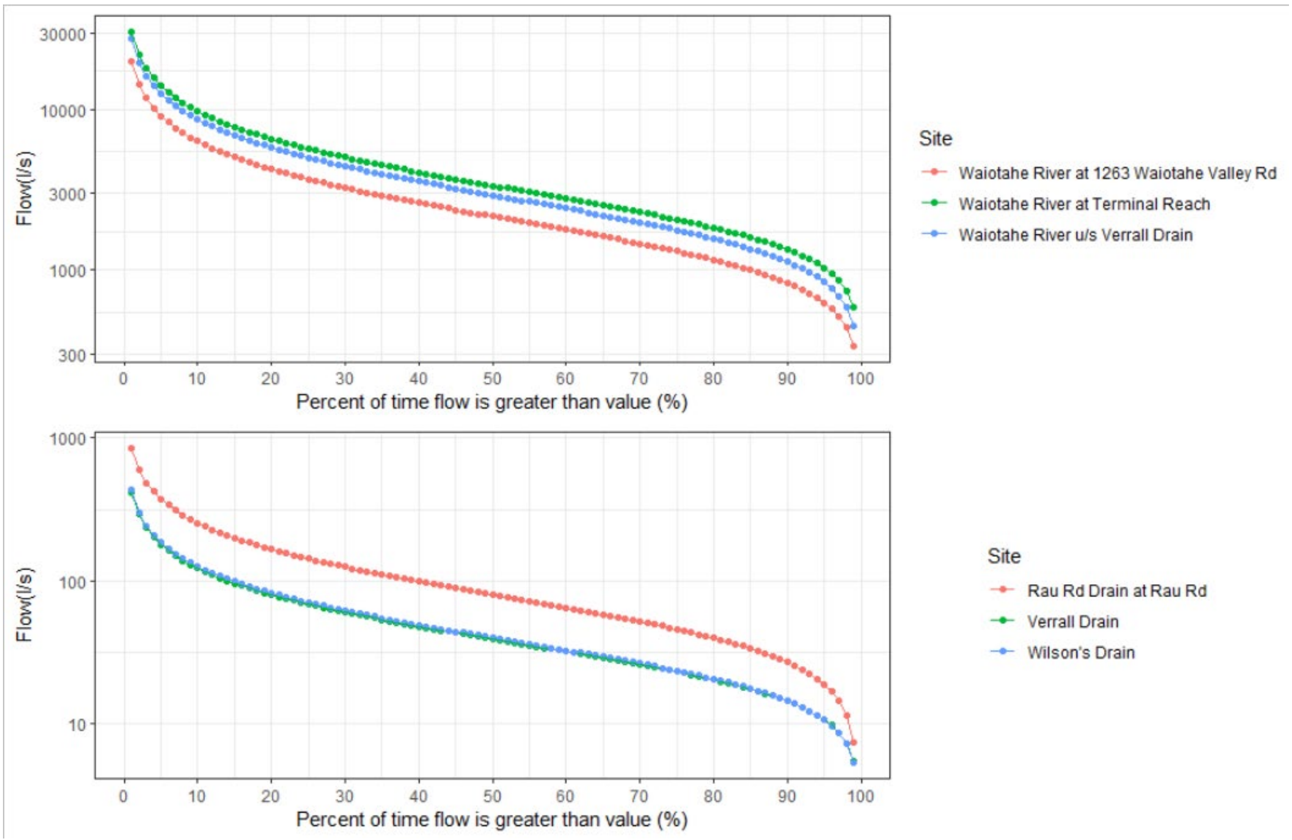

Figure 42 Comparison of FDC obtained from random forest modelling for mainstem sites (upper) and drainage sites (lower). The pink line in both plots represents the site where the master flow record was developed (i.e., the master synthetic flow site).

3 Ratios between master sites and flow-absent sites were calculated and applied to master synthetic flow to create new ‘reflected flow’ datasets for the lower catchment. - Comparison of modelled FDCs provided a ratio that could be calculated for each point of the FDC, which in turn can be applied to a flow record to create a ‘reflected’ synthetic flow record for the lower catchment (Figure 43, Figure 44). Reflected flows represent a theoretical flow that would only occur when the tide was low, i.e., the rivers and drains flowed without displacement or dilution from tides.

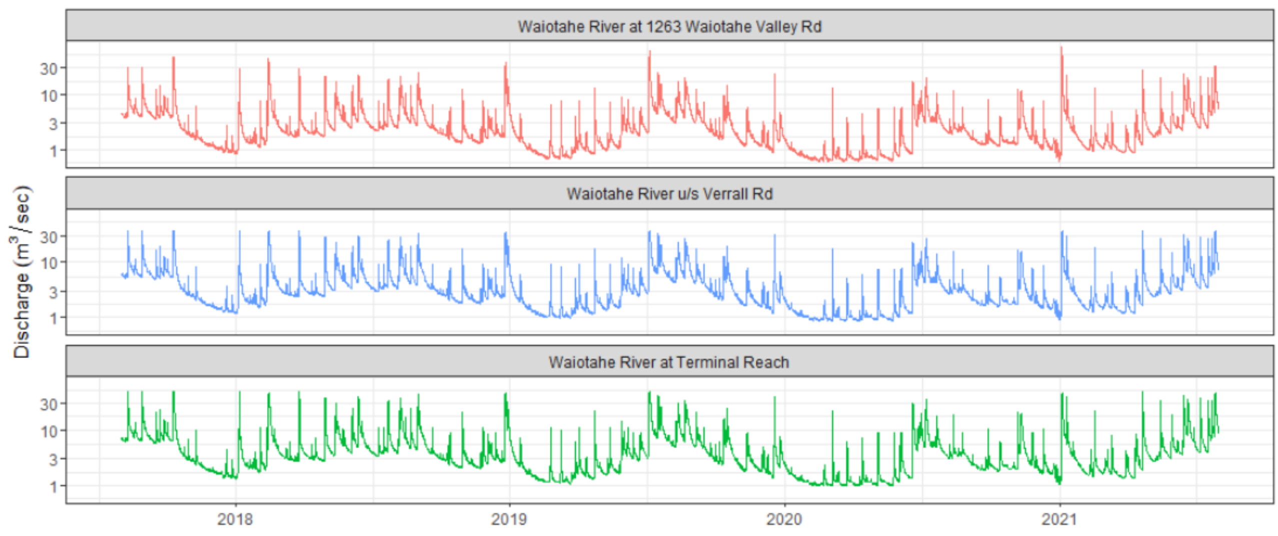

Figure 43 Reflected synthetic flows for lower catchment riverine sites. The upper catchment synthetic flow record is in the upper panel (pink).

Figure 44 Reflected synthetic flows for lower catchment drain sites. The upper catchment synthetic flow record is in the upper panel (pink).

4.9.5 LDC approach

Development of reflected synthetic flow allowed for application of the Load Duration Curve (LDC) approach for water quality sites in the lower catchment.

Waiotahe River u/s Verrall Road

The LDC analysis for Waiōtahe River u/s Verrall Road, relating to Table 9 of the NPS-FM, is shown in Figure 45. This reveals the 95th percentile numeric attribute requires the largest percentage load reduction (58%) to meet the swimmability threshold (C/D threshold in the NPS-FM). Other attributes requiring load reductions include the median (7%) and exceedance of 260 CFU (0.3%). Threshold breaches for all three numeric attributes occur during moist or high flow conditions, implying that overland flow pathways are a likely a contributing source. Another possible contaminant vector is remobilisation from upstream drains through elevated flows.

The median numeric attribute is the only attribute to show threshold breaches at lower flows, which suggests that upstream direct deposition (e.g., stock crossings or unfenced areas) may contribute to the problem.

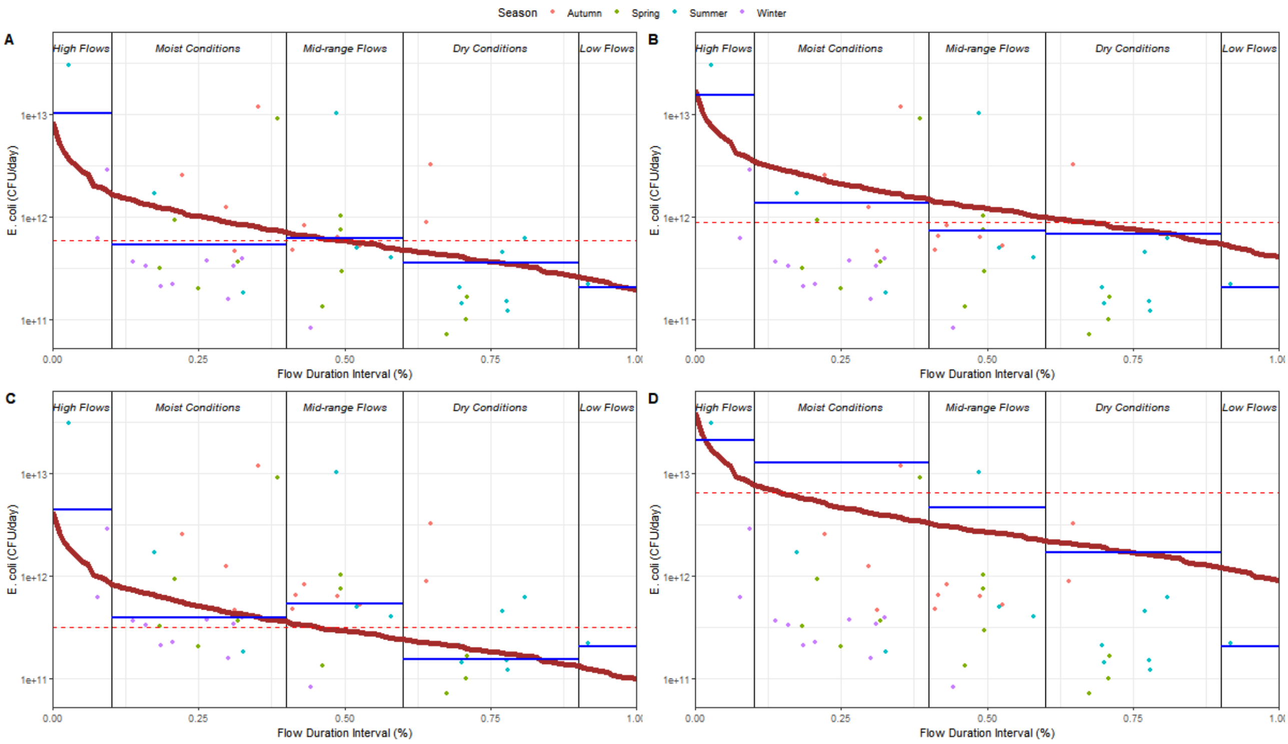

Figure 45 *Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Waiōtahe River u/s Verall Road water quality investigation site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown line represents the swimmability (C/D) threshold for each numeric attribute. Note that flow for this site was reflected from a synthetic flow record in the upper catchment.*

Table 18 *Output of the LDC analysis for the Waiōtahe River u/s Verrall Road water quality site.*

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Waiotahe River u/s Verrall Road	Low	Exc260	0
Waiotahe River u/s Verrall Road	Dry	Exc260	0
Waiotahe River u/s Verrall Road	Mid-Range	Exc260	6
Waiotahe River u/s Verrall Road	Moist	Exc260	0
Waiotahe River u/s Verrall Road	High	Exc260	73
Waiotahe River u/s Verrall Road	All	Exc260	0

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Waiotahe River u/s Verrall Road	Low	Exc540	0
Waiotahe River u/s Verrall Road	Dry	Exc540	0
Waiotahe River u/s Verrall Road	Mid-Range	Exc540	0
Waiotahe River u/s Verrall Road	Moist	Exc540	0
Waiotahe River u/s Verrall Road	High	Exc540	62
Waiotahe River u/s Verrall Road	All	Exc540	0
Waiotahe River u/s Verrall Road	Low	Median	44
Waiotahe River u/s Verrall Road	Dry	Median	0
Waiotahe River u/s Verrall Road	Mid-Range	Median	46
Waiotahe River u/s Verrall Road	Moist	Median	0
Waiotahe River u/s Verrall Road	High	Median	68
Waiotahe River u/s Verrall Road	All	Median	7
Waiotahe River u/s Verrall Road	Low	Perc95	0
Waiotahe River u/s Verrall Road	Dry	Perc95	0
Waiotahe River u/s Verrall Road	Mid-Range	Perc95	42
Waiotahe River u/s Verrall Road	Moist	Perc95	63
Waiotahe River u/s Verrall Road	High	Perc95	38
Waiotahe River u/s Verrall Road	All	Perc95	58

Verrall Drain at Waiōtahe Valley Back Road

Verrall Drain at Waiōtahe Valley Back Road is an agricultural drain and therefore unlikely to be used for recreational swimming purposes. Regardless, the E. coli attribute (Table 9) has been applied to this site to show relative differences in conditions between drains and mainstem sites.

Figure 46 shows that the Verrall Drain site breaches each of the four numeric attributes, with a 71% load reduction required to meet the worst performing exceedance of 540 CFU/100 ml attribute. Typically, exceedances occurred across all flow brackets aside from ‘low flows’, however the 95th percentile attribute was lower than the concentration threshold for ‘high flows’ which may reflect the lack of samples obtained in these conditions.

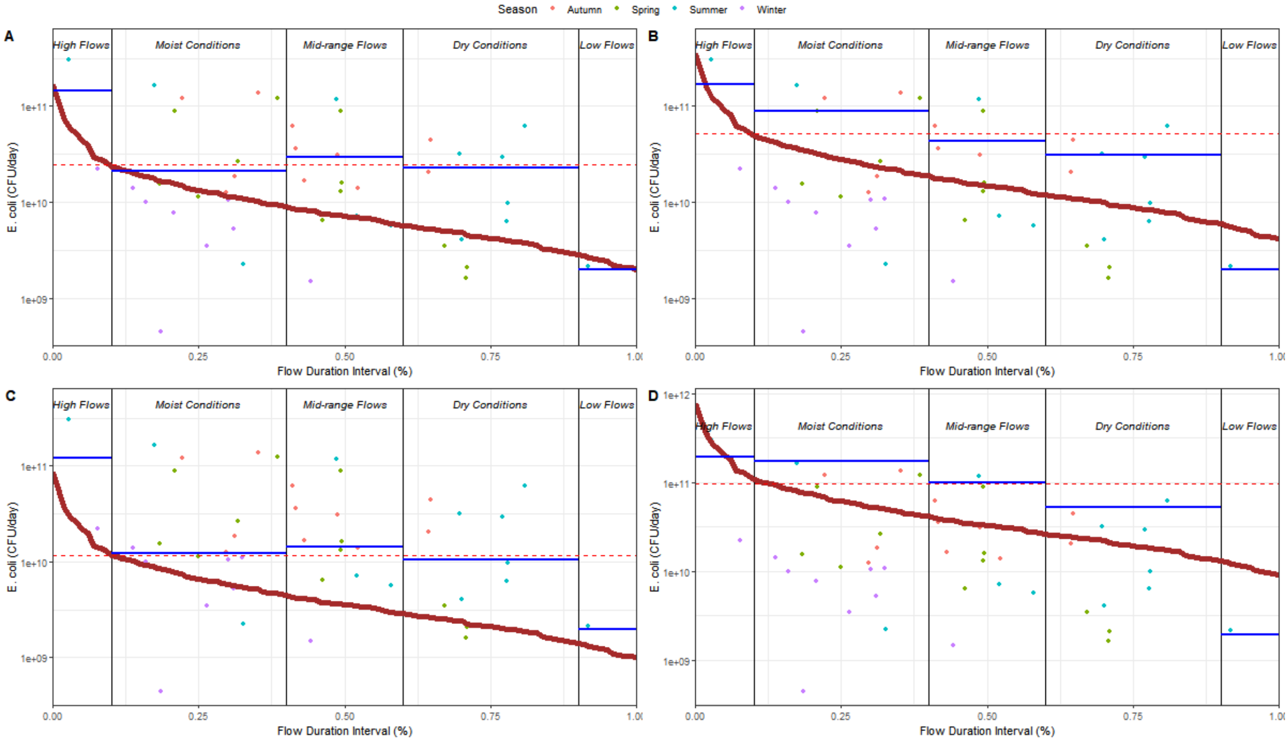

Figure 46 Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Verrall Draub at Waiōtahe Valley Back Road water quality investigation site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown line represents the swimmability (C/D) threshold for each numeric attribute. Note that flow for this site was reflected from a synthetic flow record in the upper catchment.

Table 19 Output of the LDC analysis for the Verrall Drain at Waiōtahe Valley Back Road water quality site.

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Verrall Drain at Waiotahe Valley Back Road	Low	Exc260	0
Verrall Drain at Waiotahe Valley Back Road	Dry	Exc260	82
Verrall Drain at Waiotahe Valley Back Road	Mid-Range	Exc260	75
Verrall Drain at Waiotahe Valley Back Road	Moist	Exc260	37
Verrall Drain at Waiotahe Valley Back Rd	High	Exc260	70
Verrall Drain at Waiotahe Valley Back Road	All	Exc260	71

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Verrall Drain at Waiotahe Valley Back Road	Low	Exc540	0
Verrall Drain at Waiotahe Valley Back Road	Dry	Exc540	72
Verrall Drain at Waiotahe Valley Back Road	Mid-Range	Exc540	66
Verrall Drain at Waiotahe Valley Back Road	Moist	Exc540	69
Verrall Drain at Waiotahe Valley Back Road	High	Exc540	46
Verrall Drain at Waiotahe Valley Back Road	All	Exc540	72
Verrall Drain at Waiotahe Valley Back Road	Low	Median	38
Verrall Drain at Waiotahe Valley Back Road	Dry	Median	80
Verrall Drain at Waiotahe Valley Back Road	Mid-Range	Median	75
Verrall Drain at Waiotahe Valley Back Road	Moist	Median	46
Verrall Drain at Waiotahe Valley Back Road	High	Median	81
Verrall Drain at Waiotahe Valley Back Road	All	Median	69
Verrall Drain at Waiotahe Valley Back Road	Low	Perc95	0
Verrall Drain at Waiotahe Valley Back Road	Dry	Perc95	63
Verrall Drain at Waiotahe Valley Back Road	Mid-Range	Perc95	67
Verrall Drain at Waiotahe Valley Back Road	Moist	Perc95	65
Verrall Drain at Waiotahe Valley Back Road	High	Perc95	0
Verrall Drain at Waiotahe Valley Back Road	All	Perc95	66

Wilson Drain at 16A Ōhiwa Harbour Road

Similar to Verrall Drain, Wilson Drain is unlikely to be used for recreational purposes, however LDC results have been provided below for the same reason.

Wilson Drain at 16A Ōhiwa Harbour Road showed a very similar picture to Verrall Drain where all attribute thresholds were exceeded, with a load reduction of 84% required to meet the worst performing 95th percentile attribute threshold. Similar to Verall Drain, exceedances occurred for all attributes across all but the ‘low flows’ bracket. However, there was only one sample collected during periods of low flow, so any conclusions for this flow bracket are limited until more data is collected.

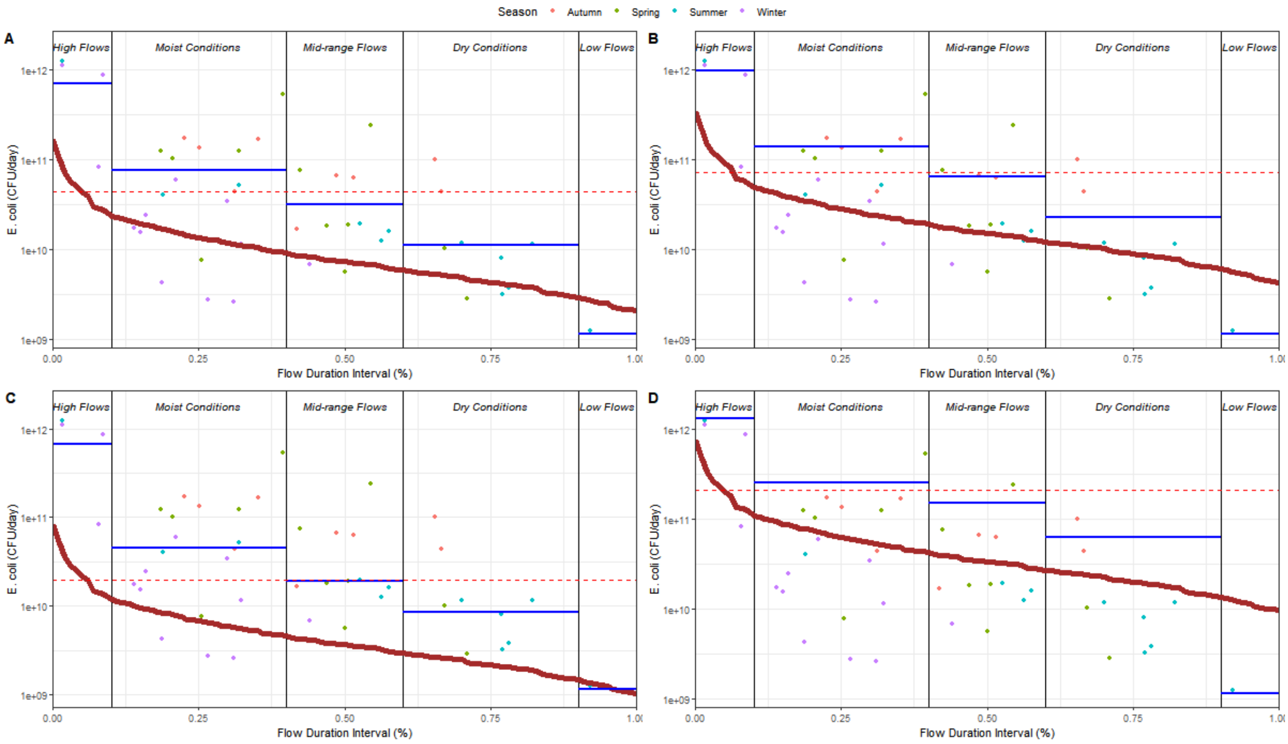

Figure 47 Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Wilson Drain at 16A Ōhiwa Harbour Road water quality investigation site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown line represents the swimmability (C/D) threshold for each numeric attribute. Note that flow for this site was reflected from a synthetic flow record in the upper catchment.

Table 20 Output of the LDC analysis for the Wilson Drain at 16A Ōhiwa Harbour Road water quality site.

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Wilson Drain at 16A Ohiwa Harbour Road	Low	Exc260	0
Wilson Drain at 16A Ohiwa Harbour Road	Dry	Exc260	61
Wilson Drain at 16A Ohiwa Harbour Road	Mid-Range	Exc260	77
Wilson Drain at 16A Ohiwa Harbour Road	Moist	Exc260	82
Wilson Drain at 16A Ohiwa Harbour Road	High	Exc260	94
Wilson Drain at 16A Ohiwa Harbour Road	All	Exc260	83
Wilson Drain at 16A Ohiwa Harbour Road	Low	Exc540	0

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Wilson Drain at 16A Ohiwa Harbour Road	Dry	Exc540	60
Wilson Drain at 16A Ohiwa Harbour Road	Mid-Range	Exc540	77
Wilson Drain at 16A Ohiwa Harbour Road	Moist	Exc540	80
Wilson Drain at 16A Ohiwa Harbour Road	High	Exc540	91
Wilson Drain at 16A Ohiwa Harbour Road	All	Exc540	79
Wilson Drain at 16A Ohiwa Harbour Road	Low	Median	0
Wilson Drain at 16A Ohiwa Harbour Road	Dry	Median	75
Wilson Drain at 16A Ohiwa Harbour Road	Mid-Range	Median	81
Wilson Drain at 16A Ohiwa Harbour Road	Moist	Median	85
Wilson Drain at 16A Ohiwa Harbour Road	High	Median	97
Wilson Drain at 16A Ohiwa Harbour Road	All	Median	81
Wilson Drain at 16A Ohiwa Harbour Road	Low	Perc95	0
Wilson Drain at 16A Ohiwa Harbour Road	Dry	Perc95	69
Wilson Drain at 16A Ohiwa Harbour Road	Mid-Range	Perc95	78
Wilson Drain at 16A Ohiwa Harbour Road	Moist	Perc95	76
Wilson Drain at 16A Ohiwa Harbour Road	High	Perc95	84
Wilson Drain at 16A Ohiwa Harbour Road	All	Perc95	84

Waiōtahe River at Waiōtahe Hall

A further mainstem water quality site was included in the LDC analysis as it was located upstream of all lowland drainage networks, and therefore should reflect faecal loading from the mid-upper catchment. There were some errors in the REC1 dataset which technically showed the Waiōtahe Hall reach as being the same as that for the mainstem Waiōtahe River u/s Verrall Road. The authors of the current study acknowledge that this is an error, and that the Verrall Road site should have greater discharge than the Waiōtahe Hall site. Regardless, it was decided to use the Verrall Road flow for the purpose of this analysis as this should provide a conservative estimate (overestimation) of the load from the upper catchment.

Figure 48 and Table 21 show that the background faecal contamination load at the Waiōtahe at Waiōtahe Hall site results in exceedance of only the median numeric attribute. This numeric attribute requires a 10% load reduction to meet the swimmability concentration threshold. Further categorisation shows that exceedances occur during all flow brackets aside from 'moist conditions', and with the greatest load reductions required at lower flows. This suggests that direct deposition or point source contamination events may be occurring upstream of the Waiōtahe Hall site, during periods of low flow when overland flow pathways are not active.

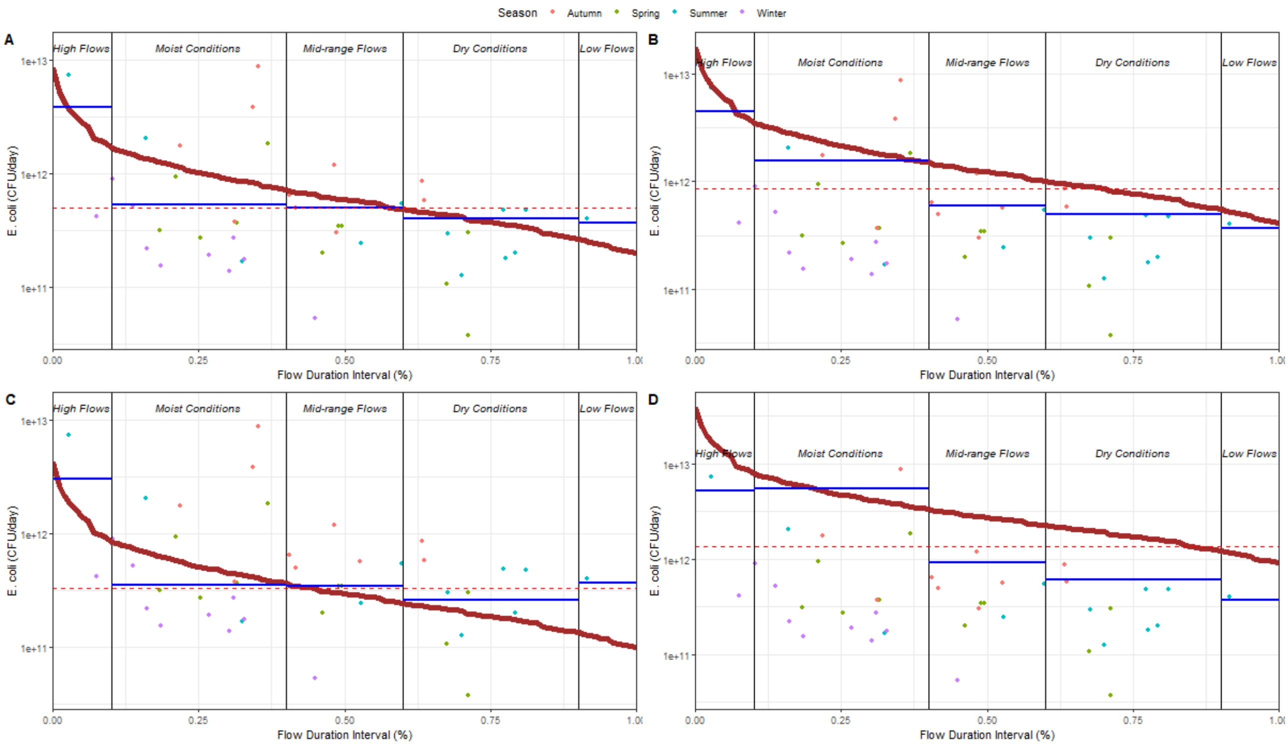

Figure 48 *Load duration curves for each numeric attribute in Table 9 of the NPS-FM, for the Waiōtahe River at Waiōtahe Hall water quality investigation site. Attributes are labelled as follows: A) percentage exceedances of 260 CFU/100 ml, B) percentage exceedances of 540 CFU/100 ml, C) median concentration, D) 95th percentile. Each figure is split into five flow bins (Low-High) defined by the underlying flow duration curve. The horizontal dashed red line represents the value of the numeric attribute across all samples in the figure, while the horizontal blue lines show the value of the numeric attribute per flow bin. The brown line represents the swimmability (C/D) threshold for each numeric attribute. Note that flow for this site was reflected from a synthetic flow record in the upper catchment.*

Table 21 *Output of the LDC analysis for the Waiōtahe River at Waiōtahe Hall water quality site.*

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Waiōtahe River at Waiōtahe Hall	Low	Exc260	37
Waiōtahe River at Waiōtahe Hall	Dry	Exc260	7
Waiōtahe River at Waiōtahe Hall	Mid-Range	Exc260	0
Waiōtahe River at Waiōtahe Hall	Moist	Exc260	0
Waiōtahe River at Waiōtahe Hall	High	Exc260	25
Waiōtahe River at Waiōtahe Hall	All	Exc260	0
Waiōtahe River at Waiōtahe Hall	Low	Exc540	0
Waiōtahe River at Waiōtahe Hall	Dry	Exc540	0
Waiōtahe River at Waiōtahe Hall	Mid-Range	Exc540	0

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Waiōtahe River at Waiōtahe Hall	Moist	Exc540	0
Waiōtahe River at Waiōtahe Hall	High	Exc540	0
Waiōtahe River at Waiōtahe Hall	All	Exc540	0
Waiōtahe River at Waiōtahe Hall	Low	Median	68
Waiōtahe River at Waiōtahe Hall	Dry	Median	28
Waiōtahe River at Waiōtahe Hall	Mid-Range	Median	13
Waiōtahe River at Waiōtahe Hall	Moist	Median	0
Waiōtahe River at Waiōtahe Hall	High	Median	53
Waiōtahe River at Waiōtahe Hall	All	Median	10
Waiōtahe River at Waiōtahe Hall	Low	Perc95	0
Waiōtahe River at Waiōtahe Hall	Dry	Perc95	0
Waiōtahe River at Waiōtahe Hall	Mid-Range	Perc95	0
Waiōtahe River at Waiōtahe Hall	Moist	Perc95	12
Waiōtahe River at Waiōtahe Hall	High	Perc95	0
Waiōtahe River at Waiōtahe Hall	All	Perc95	0

Waiōtahe River at Terminal Reach

Waiōtahe River at Terminal Reach is the last reach of the Waiōtahe River before it enters Waiōtahe Estuary. This hypothetical site was added to the analysis to demonstrate the cumulative impact of loads from adjacent drains and the lowest mainstem Waiōtahe River site. E. coli loading from Waiōtahe River u/s Verrall Road, and the two contributing drain systems; Verrall Drain at Waiōtahe Valley Black Road and Wilson Drain at 16A Ōhiwa Harbour Road, were summed and combined with a reflected synthetic flow record using the same FDC method as per other flow-absent sites.

As there was no water quality data collected at the site, the LDC method could not be directly applied. However, loads from each contributing site can be summed and expressed against a theoretical swimmability threshold based on modelled flow conditions. This is likely to slightly underestimate the overall load delivered to the terminal site as the main load component comes from the mainstem site upstream of Verrall Road, and there are likely more (unmonitored) contributions downstream. The results of this analysis are shown in Figure 49 and Table 22.

Table 22 and Figure 49 shows that the cumulative load (pink bar) exceeds the swimmability threshold when applied to the entire flow record for median and 95th percentile numeric attributes. Load reductions required to meet the swimmability target for these attributes are 54% and 3% respectively.

Further analysis shows that the 95th percentile attribute breaches the swimmability threshold during high flows and moist conditions, indicating that rainfall conditions cause faecal loads to elevate to a level that breaches NPS-FM swimmability thresholds. The median numeric attribute is breached across all flow brackets, with the exception of the moist conditions category. This suggests that there is background contamination (i.e., non-rainfall related contamination) that maintains the median numeric attribute at levels higher than the swimmability threshold at this site. An interesting observation for the median concentration attribute is that moist conditions meet the swimmability concentration threshold, which implies that there is an element of dilution occurring during this time followed by mobilisation during higher flows.

Figure 49 also shows the load contribution from different parts of the catchment over each flow bracket. This reveals the following:

- Firstly, the load from Wilson and Verrell Drain are minimal in comparison to that in the mainstem Waiōtahe River, over all flow conditions.
- This leaves the Waiōtahe River u/s Verrall Road site as the primary load contributor to the terminal reach in the catchment.
- Further upstream, the Waiōtahe at Waiōtahe Hall site has a much lower load contribution during high flows, implying that faecal contamination from the mid-upper catchment is much lower than that from the mid-lower catchment during these conditions.
- However, although dwarfed by loads at moist and high flows, the Waiōtahe River at Waiōtahe Hall site is the largest load contributor during mid-range and low-flow conditions which implies that there is background point source contamination in this area that occurs in absence of significant rainfall.

Figure 49 Cumulative E. coli loads at the terminal site (pink bar) and loads from the four water quality sites used in the LDC analysis. Results are split by NPS-FM numeric attribute (top to bottom) and by flow bracket (left to right). The red dashed line represents the swimmability concentration threshold at the terminal reach, i.e., if the combined load exceeds the red line, then the concentration at the terminal reach will be unswimmable.

Table 22 Load reductions (cumulative) required for the terminal reach to achieve swimmability thresholds.

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Combined (Waiōtahe River at Terminal Reach)	Low	Exc260	0
Combined (Waiōtahe River at Terminal Reach)	Dry	Exc260	0
Combined (Waiōtahe River at Terminal Reach)	Mid-Range	Exc260	0
Combined (Waiōtahe River at Terminal Reach)	Moist	Exc260	0
Combined (Waiōtahe River at Terminal Reach)	High	Exc260	69
Combined (Waiōtahe River at Terminal Reach)	All	Exc260	0
Combined (Waiōtahe River at Terminal Reach)	Low	Exc540	0
Combined (Waiōtahe River at Terminal Reach)	Dry	Exc540	0
Combined (Waiōtahe River at Terminal Reach)	Mid-Range	Exc540	0
Combined (Waiōtahe River at Terminal Reach)	Moist	Exc540	0
Combined (Waiōtahe River at Terminal Reach)	High	Exc540	57
Combined (Waiōtahe River at Terminal Reach)	All	Exc540	0
Combined (Waiōtahe River at Terminal Reach)	Low	Median	38
Combined (Waiōtahe River at Terminal Reach)	Dry	Median	37
Combined (Waiōtahe River at Terminal Reach)	Mid-Range	Median	37
Combined (Waiōtahe River at Terminal Reach)	Moist	Median	0
Combined (Waiōtahe River at Terminal Reach)	High	Median	67
Combined (Waiōtahe River at Terminal Reach)	All	Median	3
Combined (Waiōtahe River at Terminal Reach)	Low	Perc95	0
Combined (Waiōtahe River at Terminal Reach)	Dry	Perc95	0
Combined (Waiōtahe River at Terminal Reach)	Mid-Range	Perc95	0
Combined (Waiōtahe River at Terminal Reach)	Moist	Perc95	59
Combined (Waiōtahe River at Terminal Reach)	High	Perc95	29
Combined (Waiōtahe River at Terminal Reach)	All	Perc95	54

4.9.6 Relevance to shellfish harvesting guidelines

Load reductions calculated so far in the analysis above are only relevant to swimmability guidelines within the mainstem Waiotahe River. There is an assumption that improvement to meet NPS-FM guidelines within the main river body will have a positive effect on conditions at the shellfish harvesting site, however the load reduction to meet shellfish harvesting guidelines has not been calculated thus far. The reason being that river water is mixed with oceanic water as it enters the estuary, and local hydrodynamic processes create a heterogenous waterbody that is difficult to predict without complicated, and costly, hydrodynamic models.

In response to the situation described above a short analysis was undertaken in an attempt to simplify the hydrodynamic complexity of Waiōtahe Estuary using a modelling tool developed by Plew et al.(2018). This tool incorporates a number of simple steps that allow the user to apply the most appropriate estuary dilution model based on the physical and morphological characteristics of the subject estuary. The selected dilution model then provides a method to convert an inflow tracer concentration (e.g., *E. coli*) to within-estuary concentrations. This tool is applied in the Catchment Land Use for Environmental Sustainability (CLUES) estuaries module (Plew et al., 2015), which converts catchment derived contaminant loads into estuarine concentrations, which can, in-turn, be used to calculate estuarine trophic state through the Estuary Trophic Index Tool (Robertson et al., 2016).

The major caveat of this approach is that simplified dilution models treat each estuarine receiving environment as a homogenous water body, which is unrealistic in most instances. However, this approach has the advantage of requiring minimal data-input compared with complex hydrodynamic models which can be extremely 'data-hungry'. For this reason, dilution models are often used for initial assessments or screening purposes across multiple estuaries (Plew et al., 2018).

The lack of data to incorporate into a hydrodynamic model, and limited human, financial, and time resources, were key reasons to apply the dilution model approach to Waiōtahe Estuary. However, rather than trying to understand estuarine concentrations for in-stream concentrations derived from catchment loads, the dilution model was used to back-calculate the in-stream concentration limit that would result in estuarine conditions that meet shellfish harvesting guidelines in the MWQG (MfE, 2003). This information could then be incorporated into the LDC approach used in previous sections of this report, which provides load reductions required to meet concentration thresholds across five flow brackets.

Therefore, the unique/bespoke steps to determining load reductions to meet shellfish harvesting guidelines specifically for Waiōtahe Estuary are as follows:

1 **Use the tool developed by Plew et al (2018) to determine the correct dilution model to use for Waiōtahe Estuary**. - Using the decision tree shown in Figure 50 and the table of relevant parameters in Table 23, the Luketina dilution model was found to be the most appropriate for Waiōtahe Estuary.

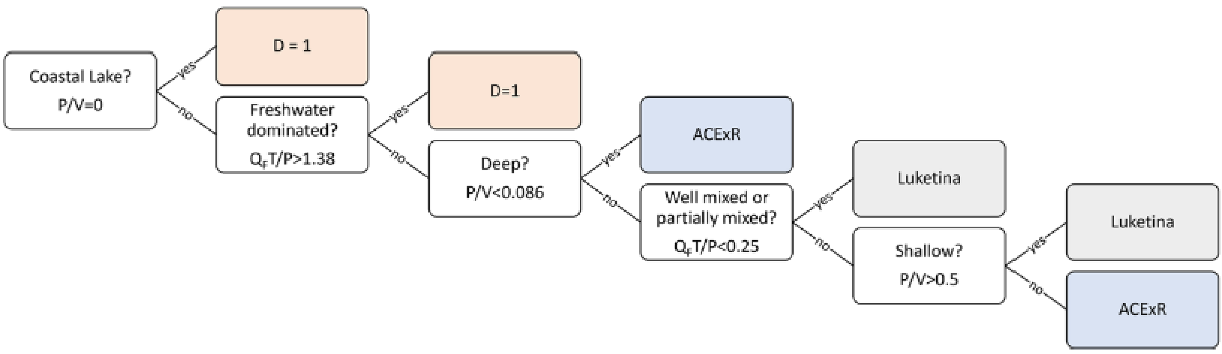

Figure 50 Estuary model selection decision tree (from D. R. Plew et al., 2018).

Table 23 Estuarine parameters for determining the correct dilution model.

Parameter	Description	Unit	Value	Source of Parameter
Q_F	Freshwater inflow	$m^3 s^{-1}$	3.00	Median flow calculated from the FDC used in this report.
T	Tidal period	s	44700	Constant
P	Tidal prism	m^3	892000	Estuary Trophic Index Dataset (*The New Zealand Estuary Trophic Index*, 2017)
V	Estuary volume at low tide	m^3	606000	Estuary Trophic Index Dataset (*The New Zealand Estuary Trophic Index*, 2017)

1 **Calculate the dilution factor (D) specific to Waiōtahe Estuary -** The dilution factor is calculated using Eq. 1 which incorporates the tidal prism (P), average freshwater inflow volume (QF) (Table 23) and a 'tuning factor' (b). The tuning factor (b) is calculated using Eq. 2 where (QF), (T), and (P) come from Table 23, (So) represents oceanic salinity, and (SE) represents estuarine salinity (Table 24 Eq. 2 and Eq. 1 result in a tuning factor (b) of 0.80 and a dilution factor (D) of 2.23 for Waiōtahe Estuary..

$$D = \frac{P(1-b) + \frac{Q_F T}{2}(1+b)}{Q_F T} \qquad \textit{Eq. 1}$$

$$b = \frac{Q_F T\left(\frac{S_O}{S_O - S_E} - \frac{1}{2}\right) - P}{\frac{Q_F T}{2} - P} \qquad \textit{Eq. 2}$$

Table 24 Additional estuarine parameters used to calculate the dilution factor (D).

Parameter	Description	Unit	Value	Source of Parameter
S_O	Oceanic salinity	ppt	31	Estuary Trophic Index Dataset
S_E	Estuarine salinity	ppt	17.1	Estuary Trophic Index Dataset

1 **Restructure the dilution model equation and solve to provide inflow (riverine) concentration for a given estuarine concentration threshold** – Plew et al (2018) provide the formula in *Eq. 3* for determining the estuarine concentration of a tracer (C_E) for a given inflow concentration (C_R), dilution factor (D), and oceanic concentration (C_O). This can be restructured into *Eq. 4* where (C_R) becomes the subject.

The oceanic concentration (C_O) was obtained by averaging Enterococci concentrations measured at the 'Opotiki Transect at 10m depth contour' monitoring site, and then converting this number to faecal coliforms using *Eq. 5* obtained from the faecal contamination comparison work by Scholes (2018a) for Waihī Estuary.

Eq. 4 can be used to calculate two riverine (inflow) concentrations that will be diluted to equal the two estuarine PMAS threshold values for shellfish harvesting. The 90th percentile threshold (no more than 10% of samples >43 CFU Faecal Coliforms/100 ml) becomes **94 CFU FC/100 ml**, while the median threshold (14 CFU FC/100 ml) becomes **30 CFU FC/100 ml**.

$$C_E = \frac{C_R}{D} + C_O(1 - \frac{1}{D})$$ *Eq. 3*

$$C_R = C_E D - DC_O + C_O$$ *Eq. 4*

$$\log(C_{FC}) = 1.0659 \log(C_{ENT})$$ *Eq. 5*

Table 25 Inflow and oceanic parameters used to calculate the inflow (riverine) concentration (C_R).

Parameter	Description	Unit	Value	Source of Parameter
C_E	Concentration of Faecal Coliforms in estuarine water.	$m^3 s^{-1}$	14 (median) 43 (90th percentile)	PMAS (from MWQG (MfE, 2003)).
C_O	Concentration of Faecal Coliforms in ocean water.	CFU	1.36	Converted from Enterococci obtained from 'Ōpōtiki Transect at 10m depth contour' NL441803.

1 **Convert the calculated inflow concentrations (pre dilution) from Faecal Coliforms into *E. coli* -** Scholes (2018a) compared Faecal Coliform and *E. coli* concentrations in Waihī and Maketū Estuaries and established the relationship shown in *Eq. 6***.**

Using the inflow concentration (C_R) (calculated in step 3) as (C_{FC}), we can establish that the *E. coli* concentration to meet the 90th percentile value of 43 CFU FC/100ml within the estuary is **79 CFU *E. coli*/100 ml**, while the median threshold of 14 CFU FC/100ml equates to **26 CFU *E. coli*/100 ml**.

$$C_{ECOLI} = 0.8213 C_{FC} + 1.7896$$ *Eq. 6*

2 **Use the *E. coli* inflow (riverine) concentrations as a concentration threshold for the LDC method –** this will allow load reductions required to achieve the concentration thresholds to be calculated overall, and for the five pre-specified flow brackets.

Results from the LDC analysis for the terminal reach, using *E. coli* concentrations that are translated from shellfish harvesting guidelines within the estuary, are shown in Figure 51 and Table 26. These show that the combined load at the terminal Waiōtahe reach (before entering the estuary) exceeds the calculated concentration thresholds that would meet shellfish harvesting guidelines within the estuary, across all flow brackets, for both threshold statistics. The 'high' flow bracket exceeds the concentration threshold by the greatest margin for both the 90th percentile and median statistics, followed by the 'moist' bracket for the 90th percentile, and 'mid-range' for the median. In general, the 90th percentile statistic is exceeded by a greater magnitude during higher flows but reduces significantly from the 'mid-range' to 'low' flow brackets, while the median statistic is highest at 'high' flows but remains constantly elevated (at a reduced level) for the remaining four flow brackets. These results show that reductions of loads at higher flows need to be prioritised to meet the 90th percentile threshold. However, if this is achieved, there will still be a background load of lower magnitude that will continue to breach the median threshold so further reduction of loads during all flows will be needed.

Figure 51 provides information on the source of the load reaching the terminal reach. As for the NPS-FM LDC analysis, there is a large load increase between the 'Waiōtahe at Waiotahe Hall' site and the 'Waiōtahe u/s Verrell Drain' site during the 'high' flow bracket. This implies that there is likely to be a major input between these sites that contributes during these flow conditions.

Load reductions across all flow conditions to meet shellfish harvesting guidelines equate to 80% to meet the median shellfish harvesting threshold, and 93% to meet the 90th percentile target. These numbers should be used for indicative purposes only due to the nature of this analysis and the limited data available. However, the magnitude of these reductions should provide justification to invest in a coupled catchment-hydrodynamic model in the future so more certainty around load reductions required can be obtained.

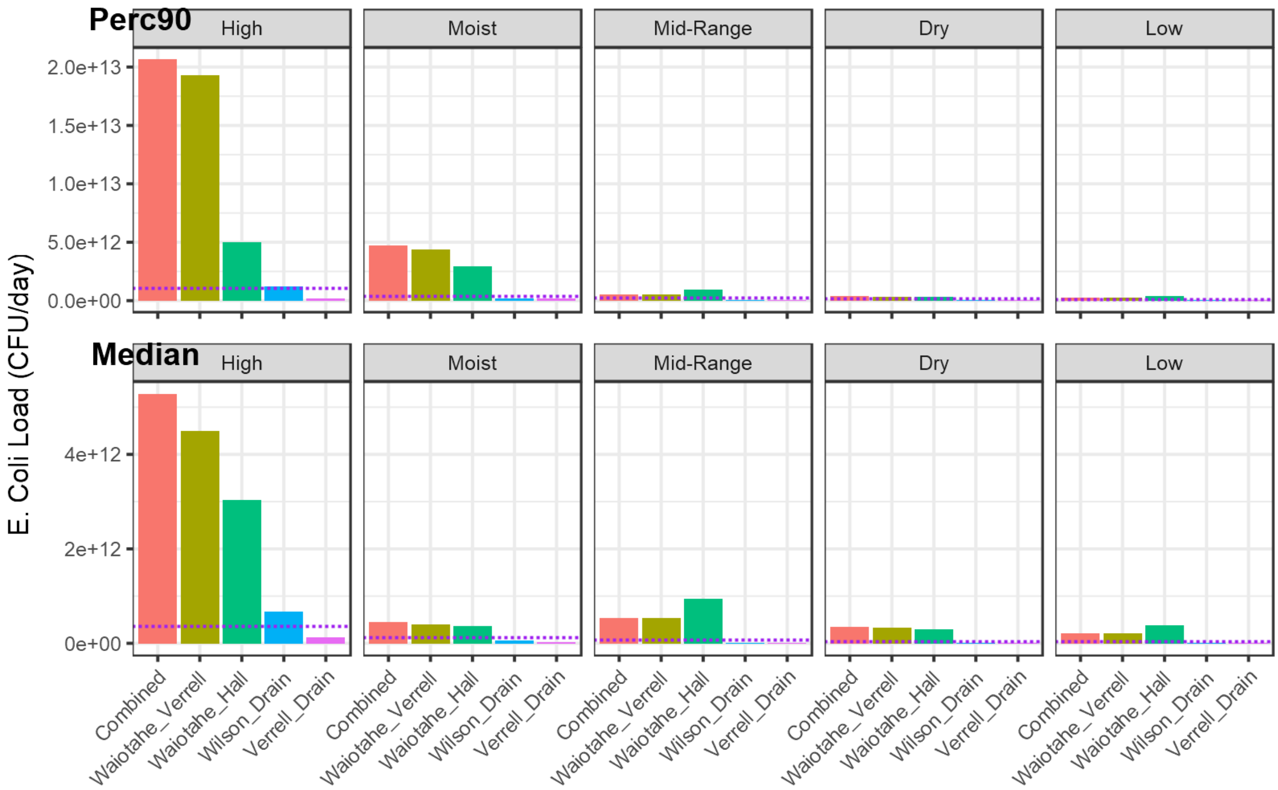

Figure 51 Cumulative E. coli loads at the terminal site (pink bar) and loads from the four water quality sites used in the LDC analysis. Results are split by the two statistics that make up the PMAS shellfish harvesting thresholds. The purple dashed line represents the concentration required to meet the stated threshold at the terminal reach, i.e., if the combined load exceeds the purple line, then the concentration at the terminal reach will cause Faecal Coliform concentrations within the estuary to exceed PMAS thresholds for shellfish harvesting.

Table 26 Load reductions (cumulative) required for the terminal reach to achieve PMAS shellfish harvesting thresholds within Waihī Estuary.

Site	Flow Bin	Numeric Attribute	Load Reduction to Meet Guideline (%)
Combined (Waiōtahe River at Terminal Reach)	Low	Estuarine Shellfish - Median	88
Combined (Waiōtahe River at Terminal Reach)	Dry	Estuarine Shellfish - Median	87
Combined (Waiōtahe River at Terminal Reach)	Mid-Range	Estuarine Shellfish - Median	87
Combined (Waiōtahe River at Terminal Reach)	Moist	Estuarine Shellfish - Median	74
Combined (Waiōtahe River at Terminal Reach)	High	Estuarine Shellfish - Median	93
Combined (Waiōtahe River at Terminal Reach)	All	Estuarine Shellfish - Median	81
Combined (Waiōtahe River at Terminal Reach)	Low	Estuarine Shellfish – Perc90	62
Combined (Waiōtahe River at Terminal Reach)	Dry	Estuarine Shellfish – Perc90	62
Combined (Waiōtahe River at Terminal Reach)	Mid-Range	Estuarine Shellfish – Perc90	61
Combined (Waiōtahe River at Terminal Reach)	Moist	Estuarine Shellfish – Perc90	92
Combined (Waiōtahe River at Terminal Reach)	High	Estuarine Shellfish – Perc90	95
Combined (Waiōtahe River at Terminal Reach)	All	Estuarine Shellfish – Perc90	93

4.9.7 Knowledge to date

- Verrall and Wilson Drain have elevated concentrations of *E. coli* which makes them unswimmable in most conditions. These drains would require a load reduction in the order of 70%-80% to make them swimmable. However, cumulative load analysis shows that these drains have only a minor contribution to the faecal load at the terminal site, even during higher flows. Additionally, as they are drains, they are unlikely to be used for swimming.
- The Waiōtahe Hall site breaches the NPS-FM swimmability threshold, but only just. This is due to elevated background concentrations in low flow conditions. This site requires a 10% reduction to meet all NPS-FM numeric attribute thresholds for swimming.
- The Waiōtahe River at Verrall Road site dominates the load supply to the terminal reach.
- The difference between Verrall Road and Waiōtahe Hall implies that a significant amount of load is generated between these sites. The only major input in this area is the Ranginui Stream which contains numerous lowland drains.
- It is estimated that the terminal site requires a load reduction of at least 54% to make this area swimmable. This would address the 95^{th} percentile attribute and the median attribute.

- The 95th percentile numeric attribute is typically exceeded during high flow or moist conditions, and the median numeric attribute is exceeded across all flow brackets but to a much lower magnitude. Although other numeric attributes (exceedance of 260 CFU/100 ml, exceedance of 540 CFU/100 ml) do not exceed the swimmability threshold at the terminal site when averaged across all flow bins, these also showed significant breaches of the swimmability threshold during periods of high flow. This implies that there is a constant background faecal loading that marginally exceeds the swimmability threshold during most flow conditions, and high flow conditions cause this loading to increase significantly.
- Exceedance conditions to meet PMAS thresholds for shellfish harvesting follow the same pattern as for swimmability guidelines, i.e., large exceedances during high and moist conditions. However, the required low concentration to meet the median PMAS threshold within the estuary results in exceedances during mid-range to low flow conditions as well.
- It is estimated that a load reduction of 93% is required to meet both PMAS thresholds for shellfish harvesting in the future.

4.9.8 Knowledge gaps

- There are only a few samples collected in Wilson and Verrall Drain during high flow or low flow periods. This may provide a false understanding of *E. coli* load during high flow events.
- Perhaps the largest knowledge gap in this catchment is the lack of discharge data in the lower river and drainage network reaches. This necessitated use of synthetic flow estimates in this report.
- This work provides rough estimates of load reductions to meet shellfish harvesting thresholds within Waiōtahe Estuary. However, the methods used: a) are based on synthetic flow relationships; and b) oversimplify the hydrodynamic complexity of Waiōtahe Estuary. A more detailed analysis, involving more robust hydrological data from the catchment and more detailed consideration of hydrodynamic processes within the estuary, is required to reduce uncertainty and refine these estimates.
- It is unknown if high levels of faecal contamination during periodic high flows, or lower levels of contamination during normal flow conditions, are more linked to accumulation of pathogenic viruses and protozoa in shellfish flesh. This may provide some insight over whether it's more appropriate to attempt load reductions during normal flow conditions, or to address the much harder task of minimising contaminant loss during storm events.

4.9.9 Recommended future work

- Perhaps the most important piece of work for the Waiōtahe Catchment is to accurately model flows for the lower catchment. The current study used a simple ratio approach based on FDC's; however more accurate models are likely to be available. This would allow more accurate estimation of loads to Waiōtahe Estuary.
- A hydrodynamic model could provide important information regarding required *E. coli* load reductions to meet shellfish harvesting guidelines within the estuary. This piece of work, coupled with more accurate flows, would significantly improve load reduction estimates.
- A catchment *E. coli* model would help land managers better understand how land-use could be changed to ensure that shellfish harvesting guidelines are not breached. This would be most useful with an accurate flow model for the lower catchment, and a hydrodynamic model for the estuary.

- A simple investigation into data collected within the Ranginui Stream Catchment could provide more information on the contribution of *E. coli* load from this area.
- More information should be obtained from the Waiōtahe at Waiōtahe Hall site to better understand the cause of elevated results during non-rainfall events.

Part 5:
Summary Discussion

The current report proposes two new attribute tables for estuarine environments where freshwater inflows may impact CRE values. For the purpose of this report, recreational bathing and shellfish harvesting were adopted as focus CRE values due to high community interest and the abundance of data available through the Recreational Bathing Programme which runs from October to April each summer. Each attribute table was based on guidance contained within the MWQG (MfE, 2003), and PMAS thresholds were allocated based on expert guidance to represent the minimum acceptable state for each CRE value. Sites that breached PMAS thresholds were further investigated to identify probable sources of contamination to the CRE objective site.

Assessment of recreational bathing and shellfish data collected between 1 July 2016 and 1 July 2021 showed that nine of the 11 (82%) shellfish harvesting sites breached at least one PMAS threshold. However, estuarine and coastal bathing sites fared much better with no breaches over the assessed period. Each of the nine PMAS breaching shellfish harvesting sites progressed to a 'site-specific investigation' phase where all available information was used to determine the likely source of faecal contamination at each site. Information used in this phase of the report was not originally collected for the purpose of linking faecal contaminant sources to CRE objective sites; however, innovative analytical methods were able to draw conclusions about certain parts of the system (e.g., inflows) and provide some overall context to the problem. However, due to the nature of available data and analyses conducted, there were numerous caveats associated with conclusions. For this reason, each site investigation was summarised into three main sections: knowledge to date, knowledge gaps, and recommended future work, to ensure transparency and consistency for the reader.

Site investigation findings highlighted a number of contributing inflows that were in breach of instream swimmability thresholds documented in Appendix 2 of the NPS-FM (C/D threshold for Table 9 and or Fair/Poor threshold for Table 22). Faecal contaminant load reductions to these thresholds are summarised in Table 27 and range from 1% for the Tuapiro Stream to 69% for the Nukuhou River. These results relate to swimmability values within each monitored inflow only, and do not include any processes that would affect concentrations between the inflow monitoring site and the final shellfish harvesting site. This means that the benefit of inflow load reductions upon a shellfish harvesting site is assumed only, and in most cases the magnitude of improvement to shellfish harvesting areas is unknown.

Table 27 Maximum faecal contaminant load reductions calculated through the site investigation process. The 'benefit' column shows the environment that will benefit from load reduction from the specified inflow. 'Instream swimming' benefits refer to swimmability at the instream monitoring site while 'Shellfish harvesting' refers to safe harvesting at the shellfish harvesting site. Maximum load reduction shows the maximum reduction across all NPS-FM attribute statistics applied (i.e., the load reduction required to meet the swimmability threshold for all attribute statistics). 'Estimated Contribution' shows the estimated contribution of each inflow to the shellfish harvesting site, based on the DELWQ particle tracing model (Tauranga Harbour only).

Shellfish Harvesting Site	Inflow	Benefit	Max Load Reduction	Estimated Contribution (TGA only)
Waihī Beach at Three Mile Creek	Three Mile Creek	N/A	N/A	
Tauranga Harbour at Anzac Bay	Tuapiro Stream	Instream swimming	1%	9%

Shellfish Harvesting Site	Inflow	Benefit	Max Load Reduction	Estimated Contribution (TGA only)
	Waiau River	Instream swimming	59%	11%
Tauranga Harbour at Bowentown Boat Ramp	Tuapiro Stream	Instream swimming	1%	4%
	Waiau River	Instream swimming	59%	76%
Tauranga Harbour at Te Puna Waitui Reserve	Te Puna Stream	Instream swimming	0%	50%
Tauranga Harbour at Tilby Point	Wairoa River	Instream swimming	65%	94%
Waihī Estuary at Main Channel	All	Shellfish harvesting	51%	
Maketū at Surf Club	All	Shellfish harvesting	39%	
Ōhiwa Harbour at Reserve	Nukuhou River	Instream swimming	69%	
Waiōtahe at Estuary	Waiōtahe River	Instream swimming	54%	
	Waiōtahe River	Shellfish harvesting	93%	

In addition to calculation of load reductions to meet in-stream swimmability thresholds, the LDC process was able to provide diagnostic results that provide useful indicators of when faecal contamination is mobilised within inflows. These results were interpreted and summarised within each site-specific sub-section and have been combined with other contextual information (e.g., FST results) to form the summary Table 28. Most inflows showed signs of diffuse pollution occurring at higher flows as overland flow pathways activate during heavy rainfall. However, a number of inflow sites also revealed elevated loads at lower flow brackets which may be indicative of point source contamination, such as stock crossings, avian populations, or leaking septic systems.

In addition to the standard site investigation methods, some investigations included other analyses to provide further context on the faecal contamination problem. For example, the DELWQ model (Bryan & Stewart, 2022) was modified to trace hypothetical particles from major inflows as they mix and disperse throughout Tauranga Harbour. This process was carried out due to the availability of the fundamental DELWQ model, the simplicity of adding the particle tracer module, and the benefit of the information that could be obtained through better understanding of inflow mixing within the harbour. The major caveat of this approach is that the modelled particles are inert (i.e., they don't attenuate over time or distance) and therefore do not represent the true processes that occur when faecal contamination mixes throughout an estuary. Regardless, results highlighted the influence of oceanic sources at northern harbour sites, and dominance of the Wairoa River in the southern harbour, and provided a reasonable overview of the dominant inflows for each Tauranga shellfish harvesting site.

A brief field investigation into spatial differences of faecal coliform concentrations within Ōhiwa Harbour showed that concentrations were similar along the northern fringe of the harbour, although the deeper Ōhope Wharf site produced lower (more pristine) results. This raises the possibility that fine sediment around the fringes of Ōhiwa Harbour may contain adsorbed faecal contamination which is released into the water column during the sampling process, while sampling from the deeper wharf site avoids this artifact. However, more information is needed to confirm this theory. Another possibility is that faecal coliform concentrations reduce after an unknown distance from the original shellfish harvesting site. Further analysis for Ōhiwa Harbour failed to find a clear link between elevated flows on the Nukuhou River and elevated faecal coliform concentrations at the

Ōhiwa Harbour at Reserve (Boat Ramp) shellfish harvesting site, although it is assumed that improvements to the poorly performing Nukuhou River will benefit the entirety of Ōhiwa Harbour to some degree.

Finally, a synthetic flow method was used to estimate flow records in the lower Waiōtahe catchment where gauging has often been impractical. This approach assumes low tide conditions when there is no tidal displacement in the lower drainage network, and that the flow within lower catchment reaches is proportionately related to flow at sites in the upper catchment. Resultant flow records were produced and used to calculate a faecal contaminant load reduction of approximately 54% to meet in-stream swimmability thresholds. A simple dilution model was able to be applied to Waiōtahe Estuary given the simplicity of the river dominated estuarine system. This analysis estimated that faecal contaminant load reductions of approximately 93% were required to meet PMAS thresholds at the shellfish harvesting site. This estimate is made with low certainty given assumptions of catchment flow relationships and estuarine dilution that were made. Regardless, it provides an indication of the magnitude of change that is likely to be required to meet shellfish harvesting guidelines and provides justification for more detailed modelling of this catchment in the future.

Table 28 Summary faecal source diagnostics for each shellfish harvesting site.

Shellfish Harvesting Site	Faecal Source Diagnostic Summary	Section
Waihī Beach at Three Mile Creek	• Likely to be coming from Three Mile Creek. • Oceanic influences are also possible.	4.1.3
Tauranga Harbour at Anzac Bay	• Heavily dominated by oceanic sources (62%) which may contain outflow from the Wairoa River in the southern harbour. • The Waiau (11%) and Tuapiro (9%) inflows were the major local inflows contributing to the site. • The Waiau River breaches all but the 'percentage exceedance of 540 CFU' attribute statistic. Load reductions should be prioritised for higher flow bins which indicates diffuse pollution through overland flow pathways. However, numerous single sample breaches of the concentration threshold indicate occasional point-source contamination. • The Tuapiro Stream breaches the median attribute statistic only. General load reductions can be made across all flow bins for this site, although some exceedances at lower flows indicate potential point source contamination.	4.2.3
Tauranga Harbour at Bowentown Boat Ramp	• Heavily dominated by the Waiau River (76%) while the Tuapiro Stream had a minor influence (4%). • The Waiau River breaches all but the 'percentage exceedance of 540 CFU' attribute statistic. Load reductions should be prioritised for higher flow bins which indicates diffuse pollution through overland flow pathways. However, numerous single sample breaches of the concentration threshold indicate occasional point-source contamination.	4.3.3
Tauranga Harbour at Te Puna Waitui Reserve	• Heavily dominated by the Te Puna Stream (50%). The other major source comes from the Wairoa River (32%). • The Te Puna Stream has elevated faecal concentrations from the limited data collected.	4.4.3

Shellfish Harvesting Site	Faecal Source Diagnostic Summary	Section
Tauranga Harbour at Tilby Point	• Heavily dominated by the Wairoa River (94%). • Swimmability thresholds are the most restrictive for the Wairoa River (i.e., Table 22 of the NPS-FM). Load reductions should be prioritised for higher flow bins which indicates diffuse pollution through overland flow pathways. • FST results from the shellfish harvesting site show a dog signature. Samples were collected during lower flow, which may suggest that the area transitions from a local (dog) signature to a catchment signature dependant on the flow of the Wairoa River.	4.5.3
Maketū at Surf Club	• The DHI report shows loads from the Kaituna River contributed more than 90% of enterococci and faecal coliform loads from the catchment to Maketū Estuary, over the period of a year.	4.6.2
Waihī Estuary at Main Channel	• The DHI report shows that the Pongakawa River and Kaikokopu Stream contribute more than 70% of the faecal coliform loads from the catchment to Waihī Estuary.	4.7.2
Ōhiwa Harbour at Reserve	• Thought to be dominated by the Nukuhou River, but elevated results didn't align with elevated flows from this catchment. The Nukuhou River breaches all attribute statistics in Table 9 of the NPS-FM, and general load reductions can be made across all flow bins. Load reductions are typically greater for higher flow bins which indicates that diffuse pollution and overland flow pathways are a problem. • Concentrations on the northern fringe of Ōhiwa Harbour are similar to the shellfish harvesting site. Improved results at the wharf site suggests that suspended sediment may harbour faecal contaminants, or that the elevated results around the shellfish harvesting site are localised.	4.8.3
Waiōtahe at Estuary	• The Waiōtahe River breaches the median and 95th percentile attribute statistic in Table 9 of the NPS-FM. Significant load reductions are required across all flow bins to meet shellfish harvesting PMAS thresholds. This implies a constant source of faecal contamination, likely coming from the lower drainage network. Load reductions were typically higher for higher flow bins which indicates diffuse pollution through overland flow pathways.	4.9.3

Part 6: **References**

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Appendices

Appendix 1:
Site Locations

Table A1 1 Coordinates for shellfish harvesting sites.

Site ID	Easting	Northing	Location Name
CP895761	1868959	5827615	Tauranga Harbour at Te Puna Waitui Reserve
CR395919	1863958	5849190	Tauranga Harbour at Anzac Bay
CS131458	1861312	5854588	Waihi Beach at 3 Mile Creek
CS292034	1862924	5850349	Tauranga Harbour at Bowentown Boat Ramp
DP547739	1875472	5827396	Tauranga Harbour at Tilby Point
GO441583	1904414	5815835	Maketu at Surf Club
GO661503	1906617	5815039	Waihi Estuary at Main Channel
LL770939	1957708	5789391	Ohope Beach opposite Moana St
LM474063	1954743	5790635	Ohope at Surf Club
ML251726	1962517	5787266	Ohiwa Harbour at Reserve (Boat Ramp)
ML922670	1969229	5786705	Waiotahe at Estuary

Table A1 2 Coordinates for estuarine recreational bathing sites.

Site ID	Easting	Northing	Location Name
CP895761	1868959	5827615	Tauranga Harbour at Te Puna Waitui Reserve
CQ490084	1864908	5830841	Tauranga Harbour at Pahoia Beach Rd
CQ940066	1869400	5830662	Tauranga Harbour at Omokoroa Beach
CR054756	1860542	5847565	Tauranga Harbour at Tanners Point Beach
CR253528	1862533	5845284	Tauranga Harbour at Ongare Point
CR395919	1863958	5849190	Tauranga Harbour at Anzac Bay
CS292034	1862924	5850349	Tauranga Harbour at Bowentown Boat Ramp
DP547739	1875472	5827396	Tauranga Harbour at Tilby Point
DP896097	1878968	5820974	Tauranga Harbour at Waimapu Bridge
EP057968	1880567	5829686	Pilot Bay opposite Pacific Ave
EP095164	1880957	5821645	Tauranga Harbour at Maungatapu Bridge (Bathing)
GO441583	1904414	5815835	Maketu at Surf Club
GO661503	1906617	5815039	Waihi Estuary at Main Channel
LM237268	1952377	5792687	Whakatane Heads
ML251726	1962517	5787266	Ohiwa Harbour at Reserve (Boat Ramp)

Table A1 3 Coordinates for coastal recreational bathing sites.

Site ID	Easting	Northing	Location Name
CS010698	1860109	5856987	Waihi Beach at Surf Club
CS131458	1861312	5854588	Waihi Beach at 3 Mile Creek
EP886340	1888867	5823406	Papamoa Beach at Harrison's Cut
EQ065035	1880652	5830352	Mount Maunganui at Surf Club

GO701513	1907018	5815139	Pukehina at Surf Club
KM969398	1949691	5793985	Piripai at Ohuirehe Rd
LL770939	1957708	5789391	Ohope Beach opposite Moana St
LM474063	1954743	5790635	Ohope at Surf Club
ML081849	1960813	5788495	Ohope Beach at Anne St
NL243661	1972431	5786610	Waiotahe Beach at Surf Club
NL713661	1977138	5786616	Hikuwai Beach at end of Snell Rd
RO364396	2013648	5813967	Te Kaha at Maraetai Bay
SO235884	2022352	5818841	Whanarua at Whanarua Bay

Appendix 2:
Flow Concentration Relationships

Table A2 1 E. coli flow relationships for each site where a LDC was applied.