Kaiate Falls Focus Catchment water quality update

Bay of Plenty Regional Council
Environmental Publication 2022/11

Prepared by: Malea Zygadlo, Environmental Scientist

5 Quay Street
P O Box 364
Whakatāne
NEW ZEALAND

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

Acknowledgements (He mihi)

Thanks must go to Bay of Plenty Regional Council (BOPRC)/Toi Moana Land Management Officers, Charlotte Duke and Melissa Goldsworthy (Summer Assistants) and Data Services Team who collected environmental data over the last summer. This report and the recommendations in it would not have been possible without this valuable information.

Bay of Plenty Regional Council's Laboratory Team processed and analysed all the water quality samples and our thanks go to them for their dedication.

Of course, gratitude must be expressed for landowners and tāngata whenua who allowed access to many sampling sites on private properties.

Publishing Information (Mōhiohio Pānuitanga)

Prepared by/He mea whakarite nā

Malea Zygadlo (Environmental Scientist)

Approved for issue by/Kua Whakaaetia Kia Tāngia nā

Rob Donald (Science Manager)

Reviewer	Description of Change	Date
Rochelle Carter	Reviewed for content	14/09/2022
Hayden Schick	Reviewed for content	16/09/2022

Recommended citation

Zygadlo, M. (2022). Kaiate Falls Focus Catchment Water Quality Update 2022. Bay of Plenty Regional Council Environmental Publication 2022/11.

Executive summary (Whakarāpopototanga Matua)

The Focus Catchments programme was developed in response to Bay of Plenty Regional Council's Key Performance Indicator to improve swimmability in the Long-Term Plan 2018-2028, and to better align land management work programmes with the emerging Essential Freshwater policy framework from the Ministry for the Environment. Several water quality investigations were requested and actioned in 2018-2021 to accurately identify catchment-specific issues and develop appropriate actions to achieve environmental enhancement, and these investigations were reported in Zygadlo *et al*. (2021), Mahon *et al.,* (2020) and Hudson (2019).

This report provides updates on the recommended monitoring from Zygadlo *et al.* (2021) to answer specific questions on the Kaiate Catchment and further support land management activities for the Coastal Catchment Team. The remaining Focus Catchments are either reported separately or do not have sufficient new data to be reported on here. The 2021/2022 data largely reinforces the findings of previous monitoring seasons. In this report we have provided some additional analyses to explore any potential new perspectives to assist in managing the bacterial contamination in the Kaiate Catchment. Load Distribution Curves (LDC) further reinforce the bacterial contamination issue across all weather conditions, indicating that a direct source continues to be an issue for the catchment (i.e., bacterial contamination is still occurring under dry and low-flow conditions), as well as diffuse bacterial transport via runoff during rain events.

The results from the Kaiate u/s Otawera confluence site this season may have had a response to the completion of fencing in this area. The loading contribution overall has not changed, but there is a potential rainfall response with lower *E. coli* levels during dry weather, which was not apparent over the 2020/2021 monitoring season. So, while we have not observed a reduction in loading, we have some evidence of reduced contributions from direct deposition, likely as a result of the fencing. Unfortunately, as no flow relationship with the Kaiate at Kaiate Falls Road could be made, no LDC was produced for this site.

Key recommendations made here for Kaiate Falls include:

1 Partner with local iwi on communications and pest management/biodiversity survey in the Owairoa Sub-catchment. The pest management aspect should be prioritised as this sub-catchment continuously shows to be the largest contributor of load to the swim site.

2 Depending on resourcing availability, monitoring following the same programme should continue to measure any changes within the catchment. Gauging should continue for the Owairoa off Waitao Road and Kaiate u/s Otawera confluence sites.

3 Investigate results from QMRA project with MfE and ESR as they come in.

4 Investigate possibility of impact of natural variability/climatic cycles on apparent worsening of *E. coli* levels at the Kaiate at Kaiate Falls Road monitoring site.

Contents

Glossary (Kuputaka)

ANZECC – Australian and New Zealand Environment and Conservation Council. Author of the Australian and New Zealand Guidelines (ANZG) for Fresh & Marine Water Quality (2018)[1] with ARMCANZ. ANZG – Australian and New Zealand Guidelines for Fresh & Marine Water Quality, produced by ANZECC & ARMCANZ (2018)[1].

Attribute – a measurable characteristic (numeric, narrative, or both) that can be used to assess the extent to which a particular value is provided for.

Conductivity - Conductivity is an indirect measure of charged particles in water. Conductivity is commonly used to indicate the total dissolved solids in water. The more dissolved salts in the water the higher the conductivity.

DGV – Default Guideline Values for physical and chemical stressors are values used to compare the state of water quality attributes to the expected values in reference ecosystems. Reference conditions are defined as the chemical and physical conditions that can be expected in rivers and streams with minimal or no anthropogenic influence[1].

DO - Dissolved Oxygen is the measure of the concentration of oxygen dissolved in the water. Aquatic life depend on oxygen to breathe, but this nutrient decreases with the growth of other nutrients and algae in the waterway.

E. coli – *Escherichia coli* is a bacteria commonly found in the guts and faeces of warm-blooded mammals (including people) and birds. People can get sick if they drink, gather shellfish from, or swim in water that has high levels of *E. coli*. Common sources of *E. coli* bacteria are animal waste from farm stock and water fowl, storm water run-off and sewerage leaks.

MWQG – New Zealand Microbial Water Quality Guidelines.

NERMN – The Bay of Plenty Regional Councils' Natural Environment Regional Monitoring Network. Fulfils the statutory requirement of local government under the Resource Management Act (1991) to monitor and report on the State of the Environment, and to provide scientifically defensible information on the physical, chemical and biological characteristics of the natural resources of the Bay of Plenty region to assist in the preparation of BOPRC policies and plans, and monitoring of the effectiveness of such plans and policies.

pH – pH indicates the level of acidity and alkalinity on a logarithmic scale of 0 to 14, with low numbers being acidic and high numbers basic. Extreme pH causes harm to fish and invertebrates.

---

[1] *ANZECC & ARMCANZ. (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. https://www.waterquality.gov.au/anz-guidelines/guideline-values/default*

1 Introduction (Kupu Whakataki)

Kaiate Falls is a popular recreational reserve and swimming site in the Tauranga Harbour Catchment and has been monitored as part of the Bay of Plenty recreational bathing programme since 2007. A permanent health warning has been in place at Kaiate Falls since 2015 due to bacterial (*E. coli*) contamination. There has been extensive research completed across this catchment since 2015, with the intention to identify sources of contamination to improve water quality and make Kaiate Falls swimmable again.

Several Environmental Programmes are underway and have made major progress. The main objective of the plans was to remove stock from waterways and critical source areas while providing riparian buffer zones to reduce bacterial contamination entering Rangataua Bay.

1.1 Focus Catchment programme

The Focus Catchments programme was developed in response to Bay of Plenty Regional Council's (BOPRC's) Key Performance Indicator to improve swimmability in the Long-Term Plan 2018-2028, and to better align land management work programmes with the emerging Essential Freshwater policy framework from the Ministry for the Environment. Several water quality investigations were implemented between 2018-2020 to accurately identify catchment-specific issues and develop appropriate actions to achieve environmental enhancement, and these investigations have been reported in Mahon *et al.,* (2020) and Zygadlo *et al.,* (2021). Land management actions and follow-up monitoring programmes were recommended in that report and the outcomes of the subsequent water quality investigations for the Kaiate Catchment are provided in this report.

1.2 Purpose (Take)

The aim of this report is to provide results of the 2021/2022 Kaiate Catchment water quality investigation. Following the recommendations of Zygadlo *et al.,* (2021). The aims for the 2021/2022 water quality-monitoring programme in the Kaiate Catchment were to:

1. Strengthen the flow relationship between the 'control' monitoring site Owairoa off Waitao Road and the rated site at Kaiate Falls Road.
2. Monitor change particularly in the Otawera and Owairoa Sub-catchment as livestock have been removed and significant fencing/planting has occurred.
3. Update the *E. coli* load for each of the monitored sites.

1.3 Background (Kupu Whakamārama)

The historic state of water quality, in reference to swimming/recreational contact, has been poor, with the number of samples in the Action/Alert modes of the MWQG increasing (worsening) since 2014. For the last several bathing seasons, Kaiate Falls was in the "Poor" Attribute Band for *E. coli* (Primary Contact) in the National Policy Statement – Freshwater Management (NPS-FM) (MfE, 2020). Faecal Source Tracking identified a dominant ruminant (majority cattle) source of *E. coli*, with avian bacteria also present. The most significant transport pathway of faecal bacteria was identified as direct deposition into streams, with overland flow in rainfall events also contributing. The last three years of monitoring showed that the greatest proportion of bacterial contamination in the Kaiate Stream was from the Otawera Stream, specifically the Owairoa Sub-catchment. Another site was added in the upper Owairoa Stream in 2019/2020, where eDNA results included possums and birds, in contrast to the lower Owairoa site which recorded eDNA of cattle and deer. The downstream increase in both *E. coli* concentrations and loads between these two sites indicated that a large proportion of the faecal contamination in the lower Otawera Stream was sourced between the upper and lower sites on the Owairoa tributary.

The 2019/2020 summer had been particularly dry, whereas higher rainfall was experienced over the 2020/2021 summer. This allowed us to better investigate the response of the catchment following a rain event. Comparison of samples collected during rainfall and samples that weren't, showed that the Otawera Sub-catchment appeared to respond relatively strongly to rain even though relationships with flow had not previously been indicated this.

The *E. coli* loading at each site was generally higher than the previous year. This was likely due to the higher rainfall and therefore increased runoff during the sample period. However, there was no indication that exclusion of stock from the Owairoa u/s Otawera site had resulted in any benefits at that stage.

Monitoring was recommended to continue over the 2021/2022 summer as significant planting and fencing had been completed, or close to completion over the 2021 year.

2 Methodology (Huarahi)

2.1 Water quality data collection/Te Kohikohinga Raraunga Kounga Wai

Bay of Plenty Regional Council’s Summer Assistants, Coastal Catchment Land Management Team and Science Team carried out sample collection.

Physical attributes (water temperature, dissolved oxygen and conductivity) were recorded on hand-held water quality meters at the time of sample collection. Water samples were stored on ice until transported to the laboratory. Samples were processed for the parameters specified in Table 2.1, to meet the aims of the monitoring programme.

Supplementary environmental/climate data was sourced where needed. Catchment rainfall and flow analysis was sourced from Waimapu at McCarrols and Kaiate at Kaiate Falls Road monitoring sites respectively.

Site selection was the same as those used in Zygadlo *et al.* (2021) for the Kaiate Catchment. Site locations are shown in Figure 2-1.

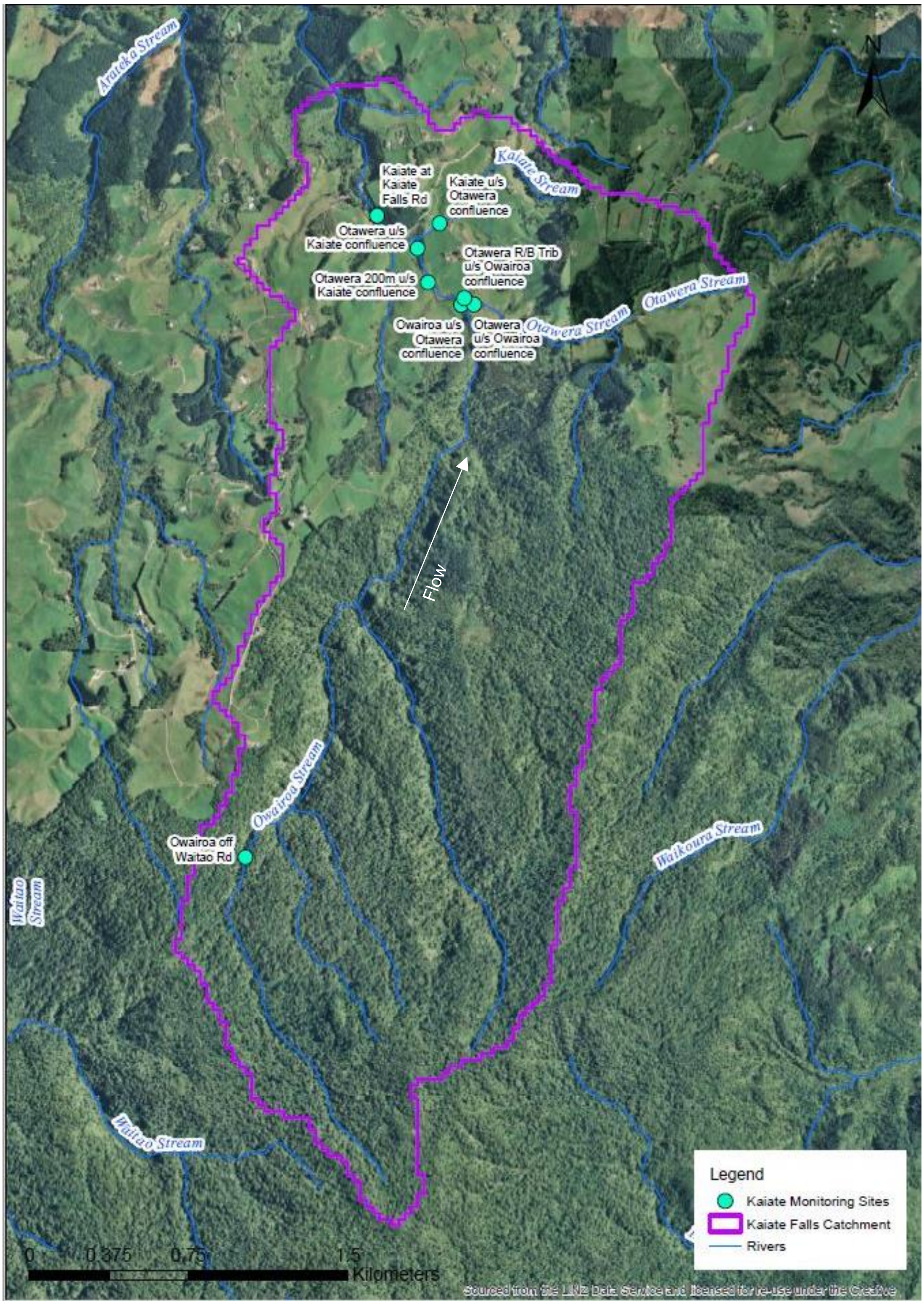

Figure 2-1 Kaiate monitoring sites for the 2021/2022 monitoring season.

2.2 Lab analyses/Ngā Tātari Taiwhanga

Analyses were performed by the BOPRC's Laboratory which holds IANZ accreditation. Table 2.1 details the methods used for chemical/biological analysis of water samples.

Table 2.1 Laboratory methods used for analyses of chemical and biological parameters in water samples

Parameter	Method	Detection Limit/Units
Turbidity	APHA 2130 B (modified) by white light turbidity meter	0.1 NTU
pH	APHA method 4500-H+ measurement at 25° C.	0.1
Conductivity	APHA Method 2510B	1 µS/cm at 25°C
Escherichia coli (E.coli)	APHA 9213D by membrane filtration (mTEC agar)	1 cfu/100 mL

2.3 Flow gauging

Flow measurements were carried out via wading gauging following the National Environmental Monitoring Standard for open channel flow measurement (NEMS, 2013) at three locations (Table 2.2). Flow relationships developed over 2019/2020 and 2020/2021 with the continuously rated Kaiate at Kaiate Falls site were utilised for the remaining sites.

Table 2.2 Stream flow measurement methods for each sampling site in 2021/2022.

Site Name	Method of flow measurement
Kaiate at Kaiate Falls Road	Rating and wading gauging
Kaiate u/s Otawera confluence	Wading gauging
Otawera u/s Kaiate confluence	Flow relationship
Otawera 200m u/s Kaiate confluence	Equivalent to Otawera u/s Kaiate confluence
Otawera R/B Tributary u/s Owairoa confluence	Flow relationship
Otawera u/s Owairoa confluence	Flow relationship
Owairoa u/s Otawera confluence	Flow relationship
Owairoa off Waitao Road	Wading gauging

2.4 Data analysis

Data was extracted from BOPRC's AQUARIUS water quality database. RStudio was used to create summary statistics and graphical representations of water quality data.

Site and catchment medians for all water quality attributes were calculated. Comparisons to appropriate guidelines and catchment medians are made.

The overall *E. coli* load was calculated by multiplying the *E. coli* concentration by the flow at the time of sampling. Site-specific flow relationships with the continuously rated Kaiate at Kaiate Falls Road site were investigated again for the sites that did not have strong enough relationships in previous seasons. Synthetic flow was generated for sites where the site-specific relationships were reliable. If a reliable relationship did not exist, then data points without a gauging were not used in the load estimates.

2.5 Load Duration Curves

Load Duration Curves (LDCs) are a method employed by the United States Environmental Protection Agency (United States Environmental Protection Agency, 2007) for calculating contaminant load reductions required for a receiving environment to meet a concentration threshold. Load Duration Curves are a 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.

Load Duration Curves are useful in the context of this study because they allow for the reader to understand the flow bracket where *E. coli* loads result in exceedances of the 550 cfu/100 mL swimmability concentration threshold set out in the New Zealand Microbiological Guidelines (MWQGs, 2003). Flow brackets are defined according to the LDC standard of the percentage of time that the flow is equalled or exceeded. Categories are as follows: low flows – minimum flow to 90th percentile; dry conditions 90^{th} to 60^{th} percentile; mid-range flows 60^{th} to 40^{th} percentile; moist conditions – 40^{th} to 10^{th} percentile; high flows – 10^{th} percentile to maximum flow.

Load Duration Curves were determined for five sites. These were sites where a reasonable flow relationship was available with the continuously rated flow at Kaiate at Kaiate Falls Road and/or they were a key site in understanding the loading contributions. To produce an LDC, the following steps were involved:

1. Calculating the FDC for each site. This required creating a continuous simulated flow dataset for each site based on the relationship with the Kaiate at Kaiate Falls Road. Hourly average flows were used form the Kaiate at Kaiate Falls Road site rather than the 15-minute readings to ensure reasonable data processing times. The FDC's were based on the 2019–2022 flow record as this is the time period that the flow relationships are based on. Data processing was done in RStudio using the hydroTSM package.
2. The LDC was calculated for the 550 cfu/100 mL swimmability threshold. This was calculated by multiplying the threshold concentration with each flow percentile in the FDC i.e., (5,500,000 cfu/m^3 * FDC flow m^3/s) * 86,400 s/day = x cfu/day.
3. Flow at sample times was assigned to the flow percentile and flow bracket of the FDC (described above).
4. This information was combined with the load results for each site and a plot produced with each of the individual sample points, 95^{th} percentile of load results for each flow bracket, and comparison of these to the LDC required to meet the 550 cfu/100 mL swimmability threshold.

2.6 Comparisons to previous research and freshwater guidelines/Huarahi

The catchment median of each attribute was calculated for simple catchment-scale comparison to guidelines and previous research. Water quality results were compared to median values for the appropriate biophysical class (adopted from Hamill *et al.,* 2020[2]). This provides context for results to similar sites in the Bay of Plenty.

Site medians were compared to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) Default Guideline Values (DGV's) for physical and chemical stressors. These guidelines were established based on reference sites throughout New Zealand in different River Environment Classifications (REC). Reference conditions are determined from locations where there is minimal or no anthropogenic influence. There are two different percentiles that are determined for the DGV for two types of stressors.

- The 80th percentile for those physical and chemical stressors that are harmful at high values (e.g. conductivity and turbidity)
- The 20th percentile for those that are harmful at low values (e.g. dissolved oxygen).

The DGV's for the warm wet low elevation REC are given in Table 2.3.

Table 2.3 ANZG physical and chemical stressor Default Guideline Values for warm wet low elevation REC class (ANZECC & ARMCANZ, 2018).

Parameter	ANZG DGV threshold	Value
Conductivity	80th percentile	115 µS/cm
Dissolved Oxygen	20th percentile	92%
pH	20th percentile	7.26
Turbidity	80th percentile	5.2 NTU

These are not toxicity thresholds, rather they are where 80% of reference sites within this REC fall below (or above for dissolved oxygen and water clarity) this value. So, values higher (worse) [or lower (worse) for dissolved oxygen] than the DGV indicate that there is 'potential risk' of adverse effects at that site and triggers the need for further investigation. It is stressed that these are the 'default' guideline values of reference condition sites, and most of the sites monitored are highly modified environments. Whist the DGVs are provided here as an indication of what the sites would have been like with minimal human impact, using local data should be favoured and this has been achieved by comparing to long-term regional water quality monitoring where appropriate data was available.

[2] Note that the biophysical classifications have gone through revision and update in Carter *et al.,* (*in prep*). However, application of them is not fully implemented at this stage. This report therefore continues to use the old classification system, but future reporting will update this reference.

The *E. coli* results were compared to the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MWQG) (MfE, 2003). Whilst it is acknowledged that not all sites sampled would be accessed for swimming, this comparison simply provides an indication of what healthy recreational contact conditions are. The sites are not compared to the NPS-FM *E. coli* attribute tables, as these sites have not been monitored in a way that was intended for NPS-FM comparison i.e., only seasonally and for a shorter period of time each season.

Table 2.4 Threshold values and implications for health of the Microbiological Water Quality Guidelines for Freshwater Recreational Areas (MfE, 2003).

MWQG Threshold	Numerical value	Implication
Acceptable	<260 cfu/100 mL	Safe for swimming
Alert	260-550 cfu/100 mL	Caution advised
Action	>550 cfu/100 mL	Unsafe for swimming

All field and sampling techniques, laboratory and data analyses followed standard BOPRC methods.

3 Results 2021/2022 (Ngā Otinga 2021/2022)

3.1 Kaiate at Kaiate Falls Road - Bathing Season

During the 2021/2022 bathing season, *E. coli* measured at Kaiate Falls Road exceeded the Action threshold value in the MWQG, of 550 cfu/100 mL, 61% of the time (see Figure 3-1). This is more or less the same as the 65% of samples over the Action threshold the previous summer monitoring period (2020/2021). Over the 2021/2022 summer, only one sample (or 4%) was below the Acceptable threshold of 260 cfu/100 mL, while samples were above the Alert threshold 35% of the time. Kaiate Falls remains in the "E" attribute band in the NPS-FM.

Recent work within BOPRC has brought to light the contribution of climatic cycles and 'natural variability' of water quality attributes. It would be interesting to understand the potential contribution of climatic cycles on the results at this site and whether it may explain some of the degradation apparent in Figure 3-1. This is not a simple process to undertake but could be investigated in the future.

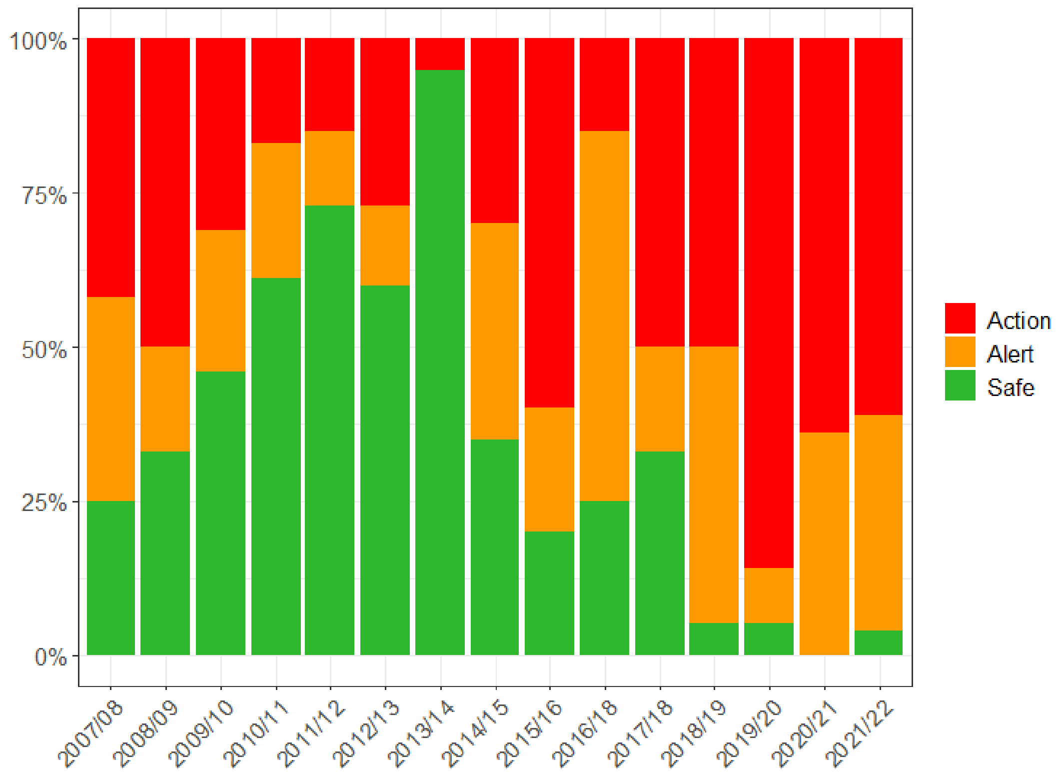

Figure 3-1 Percentage of E. coli samples at Kaiate at Kaiate Falls Road within the MWQG thresholds, 2007-2022. The coloured bands illustrate the E. coli thresholds of the MWQG.

3.2 Catchment results

Results for physical stream parameters were in line with previous results in the Kaiate Catchment. As expected, the upper site in native forest (Owairoa off Waitao Road) had the lowest median conductivity, turbidity and temperature (Figure 3-2 and Figure 3-3), in comparison to sites in the developed areas of the catchment downstream. The Kaiate u/s Otawera confluence and Otawera R/B Trib u/s Owaroa confluence both have consistent patterns of lower DO and pH and higher conductivity compared to the other sites. These sites capture two tributaries that have quite different characteristics than the other main tributaries. They are much smaller, and the upstream environment have some wetland like characteristics. These observations are therefore unsurprising.

The median *E. coli* concentration across the catchment for 2021/2022 was 590 cfu/100 mL (see Figure 3-4), which was similar to results from 2019/2020 monitoring. The catchment median for *E. coli* in 2021/2022 was also higher (worse) than the VA Steep median, as would be expected given the established history of elevated faecal contamination in the Kaiate Sub-catchment.

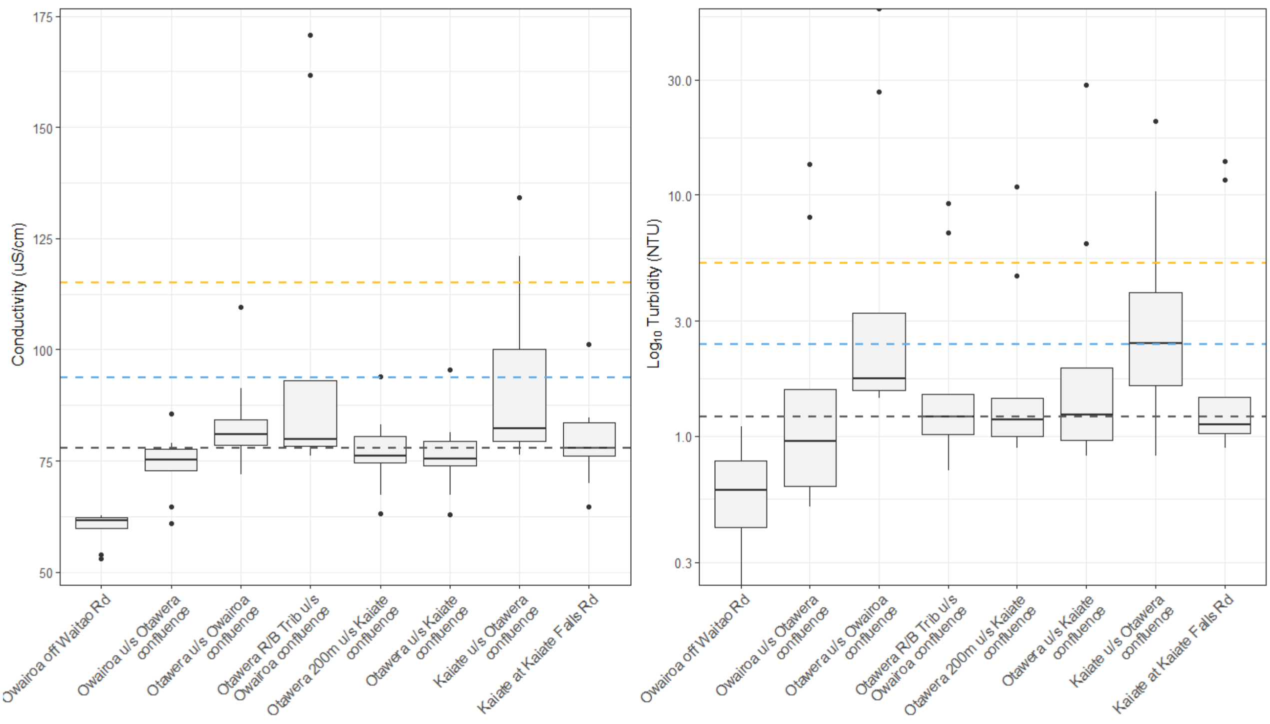

Figure 3-2 Conductivity and Turbidity results in the Kaiate Falls Catchment, 2021/2022. Comparative values shown are the ANZG DGV (yellow), the VA Steep median (blue), and the catchment median 2021/2022 (grey).

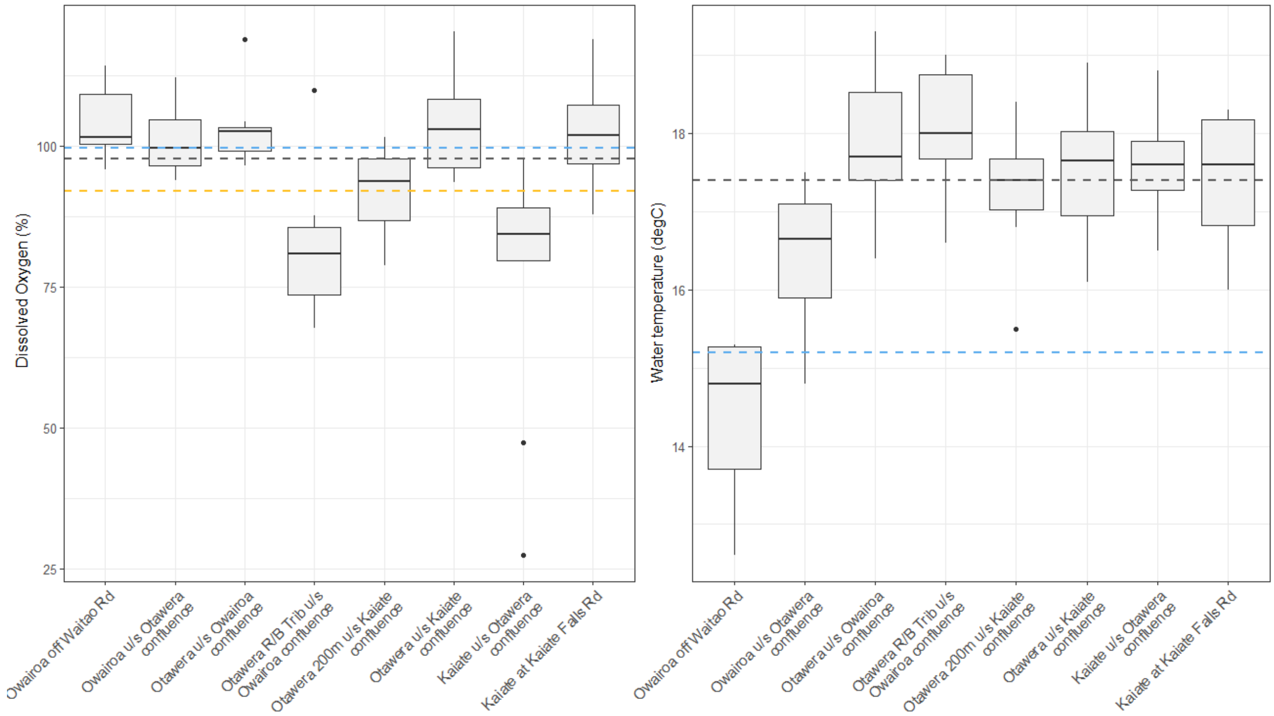

Figure 3-3 Dissolved oxygen and water temperature results in the Kaiate Falls Catchment, 2021/2022. Comparative values shown are the ANZG DGV (yellow), the VA Steep median (blue), and the catchment median 2021/2022 (grey).

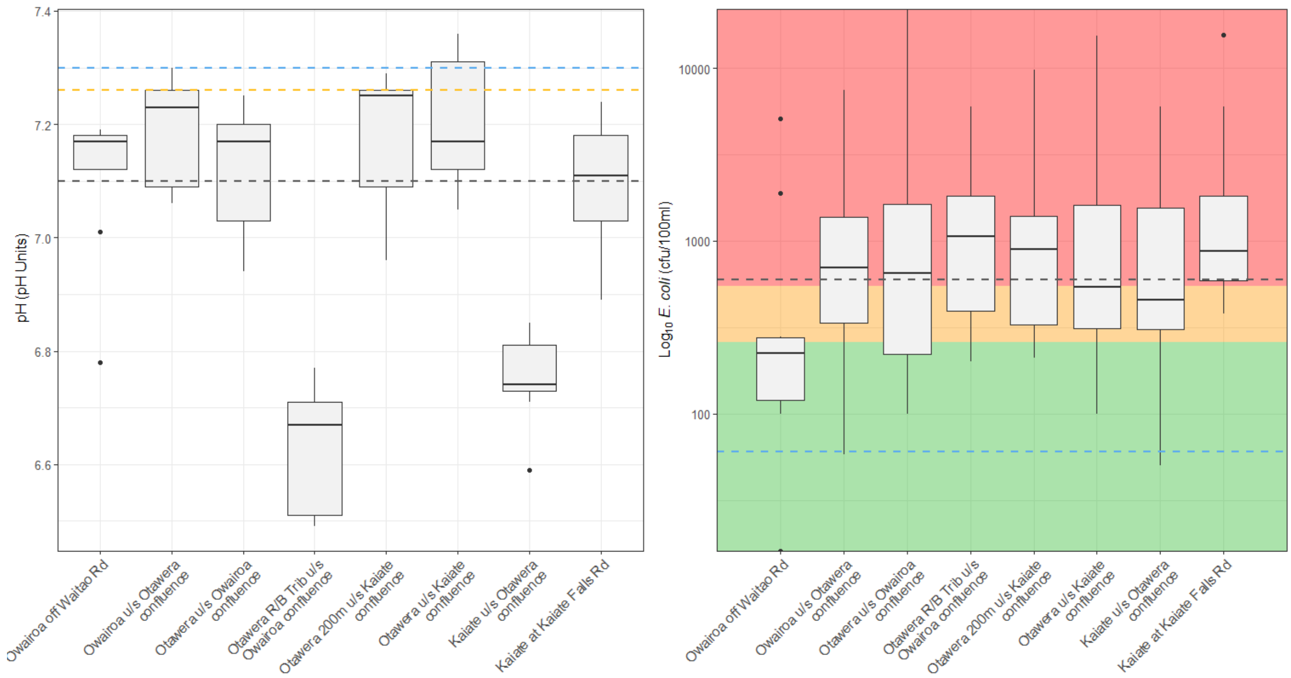

Figure 3-4 pH and E. coli concentration results in the Kaiate Falls Catchment, 2021/2022. Comparative values shown are the ANZG DGV (yellow), the VA Steep median (blue), and the catchment median 2021/22 (grey). The coloured bands illustrate the E. coli thresholds of the MWQG.

3.3 Rainfall and flow

There were three rainfall events 24 hours prior to sampling times over the 2021/2022 period, the most significant of which was 36 mm 24 hours before 8 February 2022 sampling date (see Table 3.1 and Figure 3-5). Daily rainfall over the monitoring season is shown in Figure 3-5.

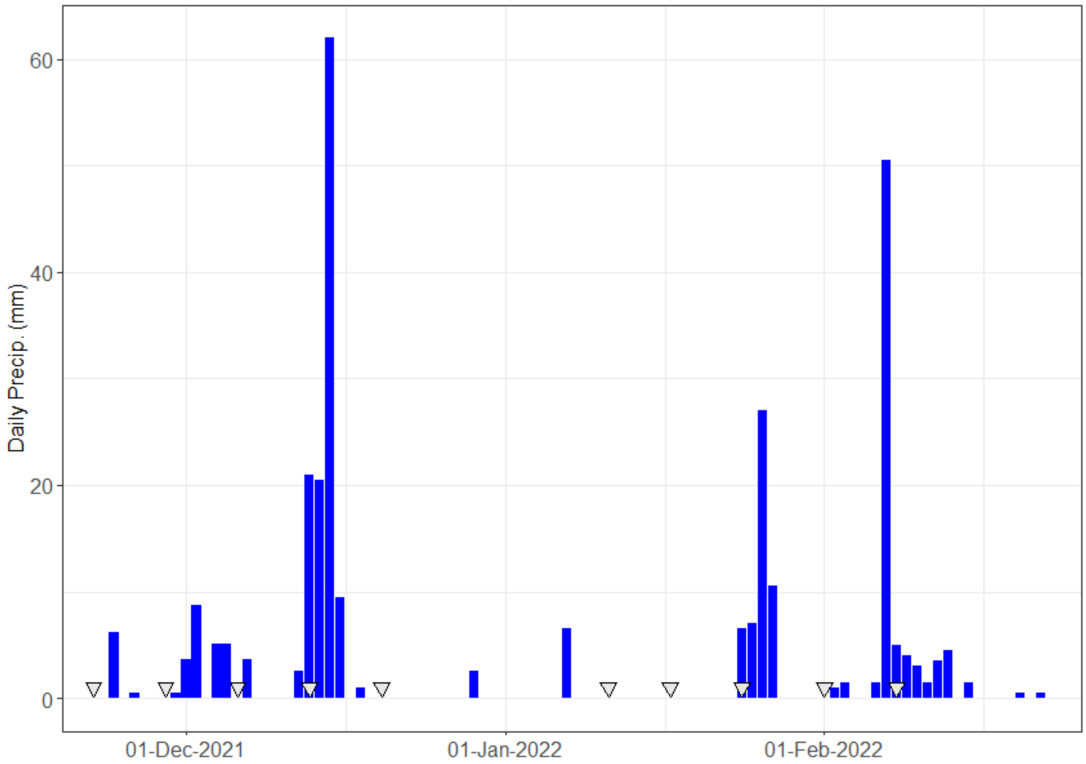

Figure 3-5 Daily rainfall at Waimapu at McCarrols between 1 November 2021 and 28 February 2022. Sample days indicated by triangles.

The water level recorder based at Kaiate Falls Road provides the most accurate information as to whether rainfall has generated overland flow, and subsequently increased the water level in the Kaiate Stream. The flow in the Kaiate Stream over three monitoring periods is shown in Figure 3-6. The recent monitoring period shows variable flows in between the recorded flows of 2019/2020 and 2020/2021, then generally higher flow following the large rain event in mid-December 2021.

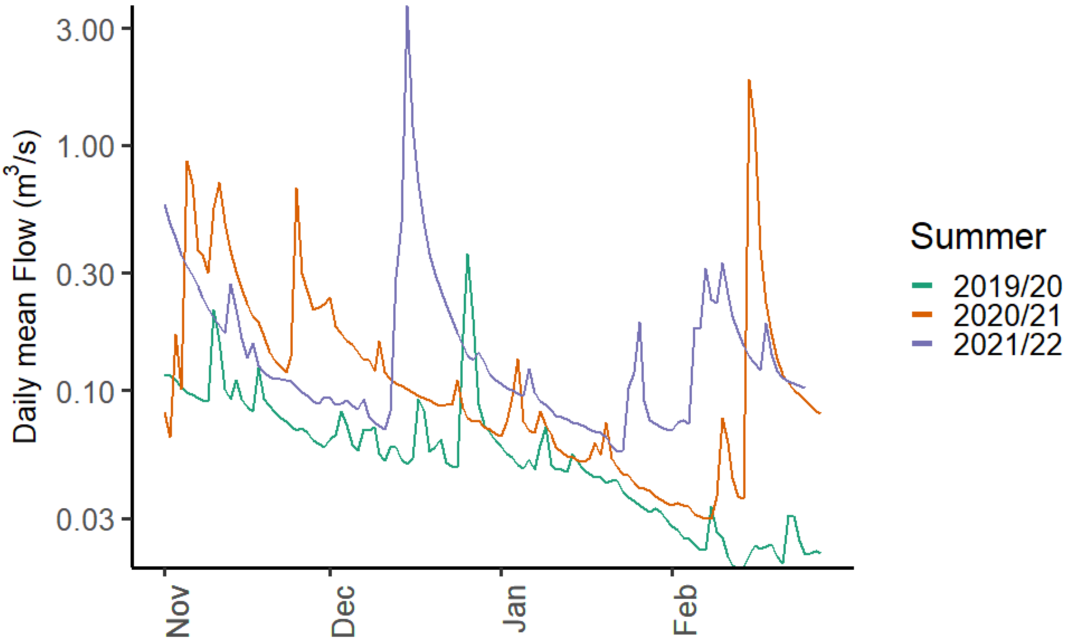

Figure 3-6 Flow at continuously rated Kaiate at Kaiate Falls Road site over the three summer monitoring periods. Note log scale of y-axis.

Similar to the 2020/2021 bathing season, the 2021/2022 season captured some rainfall events. Table 3.1 and Table 3.2 below show the *E. coli* concentrations at each site during rainfall sample days and no rainfall sample days respectively. This clearly shows the increase in contamination during or immediately after rainfall across the catchment. The control site (Owairoa off Waitao Road) has the most consistent rainfall response based on these samples.

In comparison to the 2020/2021 monitoring season, the Kaiate u/s Otawera confluence site is no longer high under all conditions. Fencing and planting on this tributary was completed during 2021. It can take many years for full benefits to be realised for reducing bacterial contamination, but the exclusion of stock from a waterway and buffer area can have an immediate impact. The lower concentrations of *E. coli* on sampling days where there was no rainfall indicate that direct deposition, i.e., stock defecating in the waterway, is no longer a dominant source of bacterial contamination compared to previous results at this site. However, the overall load has not reduced, indicating that overland flow has transported the same amount of contamination into the rivers. So, while we have not observed a reduction in loading, we have some evidence of reduced contributions from direct deposition, likely as a result of the fencing.

Table 3.1 E. coli concentrations (cfu/100 ml) at monitoring sites from the 2021/2022 monitoring programme when rain had occurred 24 hours prior to sample time. Results are colour coded to the E. coli thresholds of the MWQG (Red = Action, Orange = Alert, Green = Safe).

Date	Owairoa off Waitao Road	Owairoa u/s Otawera confluence	Otawera u/s Owairoa confluence	Otawera R/B Trib u/s Owairoa confluence	Otawera 200 m u/s Kaiate confluence	Otawera u/s Kaiate confluence	Kaiate u/s Otawera confluence	Kaiate at Kaiate Falls Road	Rainfall 24 hours prior* (mm)
13/12/2021	5100	7500	22000	6000[2]	9800	15300	6000[2]	15600	22.5-28.5[1]
24/01/2022	280	6000[2]	6000[2]	6000[2]	6000[2]	6000[2]	6000[2]	6000[2]	3-9[1]
8/02/2022	1900	1400	1200	1400	1400	1900	370	1200	36

*Rain gauge at adjacent catchment at Waimapu at McCarrols site and therefore volumes may not be wholly accurate for the Kaiate Catchment.

[1]Rainfall volume at first sample time (Owairoa off Waitao Road) to last sample time as it was raining during sampling.

[2]Indicates where samples were above the detection limits. A default of 6000 cfu/100 mL is used by the lab.

Table 3.2 E. coli concentrations (cfu/100 ml) at monitoring sites from the 2021/2022 monitoring programme when there had been no rain 24 hours prior to the sample times. Results are colour coded to the E. coli thresholds of the MWQG (Red = Action, Orange = Alert, Green = Safe).

Date	Owairoa off Waitao Road	Owairoa u/s Otawera confluence	Otawera u/s Owairoa confluence	Otawera R/B Trib u/s Owairoa confluence	Otawera 200 m u/s Kaiate confluence	Otawera u/s Kaiate confluence	Kaiate u/s Otawera confluence	Kaiate at Kaiate Falls Road
22/11/2021	16	58	230	1400	210	600	290	590
29/11/2021	120	1000	100	2000	260	210	50	590
6/12/2021	120	90	210	200	310	320	70	420
20/12/2021	200	300	220	400	380	310	420	380
11/01/2022	270	480	420	340	1000	490	1400	2100
17/01/2022	250	1300	1000	800	800	100	490	700
1/02/2022	100	490	1800	390	1400	1000	1600	1100

3.4 Flow relationships

Previous reports (Zygadlo *et al., 2021*; Mahon *et al.,* 2020) have determined flow relationships with the continuously rated site for the majority of sampling sites. At the end of the 2020/2021 monitoring season, one site (Kaiate u/s Otawera confluence) continued to show unsuitable relationships for predicting the flow. The control site (Owairoa off Waitao Road) was showing a strong relationship, but still had limited data points.

Owairoa off Waitao Road had an additional four wading gaugings measured over the 2021/2022 sampling season, providing 12 gaugings in total to investigate a relationship with the continuously rated site at Kaiate Falls Road. The additional gaugings resulted in a relationship that was better represented with an exponential regression rather than a linear regression. *Figure 3-7* shows an exponential relationship between Owairoa off Waitao Road and the continuously rated site at Kaiate at Kaiate Falls Road with an R^2 of 0.979. This relationship is logical when considering this is a comparison between the top and the bottom of the catchment. The flow at Kaiate at Kaiate Falls site is expected to initially increase faster than Owairoa off Waitao Road due to additional inputs from other tributaries. It is noted that this relationship may not hold under higher flows and this relationship should only be used for summer flows. Gauging under various seasons would need to occur to determine a relationship across the year. Loading estimates in Zygadlo *et al.,* (2021) are updated in this report to reflect this new relationship.

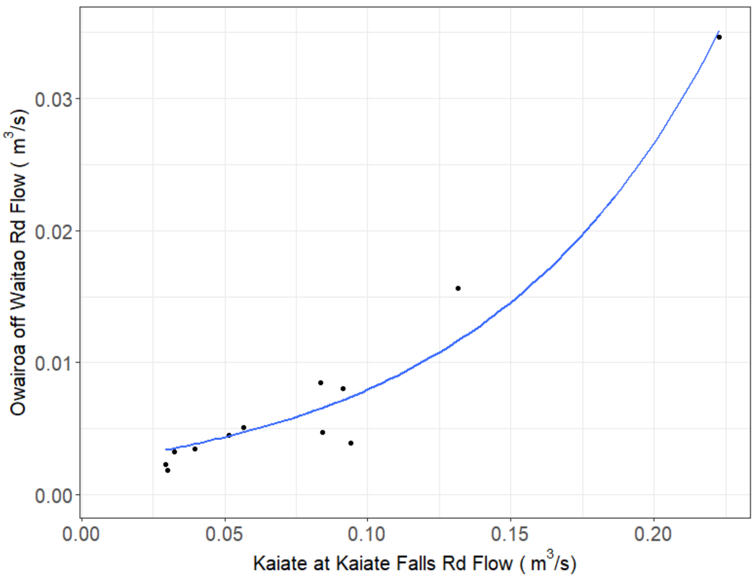

Figure 3-7 Relationship between flow at Owairoa off Waitao Road and Kaiate at Kaiate Falls Road.

In Zygadlo *et al.,* (2021), Kaiate u/s Otawera Confluence did not show a useable flow relationship. As a result, only actual gaugings were used in the load estimate calculations. The monitoring programme for 2021/2022 included wading gaugings at Kaiate u/s Otawera confluence. There was still no relationship, so only the actual gauging sample data was used again. While this is the 'main stem' of the Kaiate Stream, it is a much smaller contribution to the downstream Kaiate Falls compared to the Otawera Stream.

The catchment characteristics are also different to that of the Otawera Sub-catchment in that it has a much lower gradient resulting in a boggy environment. It is perhaps therefore unsurprising that a reliable relationship cannot be found.

3.5 E. coli load

It is difficult to predict the impact that contaminant inputs from individual sub-catchments may have on downstream water quality without the knowledge of loads. The product of flow and concentration at the time of sampling provides an estimate of the instantaneous load. Load is expressed in terms of contaminants mass (cfu) per unit of time (seconds).

The Otawera Sub-catchment previously contributed the majority of the *E. coli* load (Hudson, 2019; Mahon *et al.,* 2020; Zygadlo *et al.,* 2021). This catchment comprises the main Otawera Stream, the incoming tributary of the Owairoa Stream, and a small un-named tributary on the right bank of the Otawera Stream. The site with the highest (worst) loading contribution within the Otawera Sub-catchment is consistently the Owairoa u/s Otawera confluence site.

A comparison of the four monitoring periods is shown in *Figure 3-8*. The four periods had differing climate conditions, where the 2019/2020 period had very low rainfall and would be considered a baseflow monitoring season. The most recent 2021/2022 monitoring season had the highest rainfall. It should be noted that the most recent monitoring period has a number of samples that were above the detection limit and as such, were recorded as the default 6,000 cfu/100 mL. This value was used in the loading calculations but will likely be underestimating the true loading for that sample time.

The ‘control’ site (Owairoa off Waitao Road) showed an increase in the contribution of load from each previous season, although, these increases are not significantly different. The contribution from Kaiate u/s Otawera confluence shows large variation compared to previous years. As mentioned above, this site is no longer showing high concentrations under all conditions. Some of the dry weather samples had concentrations <100 cfu/100 ml, yet there are still some high results, particularly under wet weather sampling conditions. This shift could be reflective of the completion of fencing and planting of this tributary removing the direct deposition of faecal contamination from stock under dry conditions.

Overall, the Owairoa Sub-catchment still contributes the largest load to the Kaiate at Kaiate Falls site.

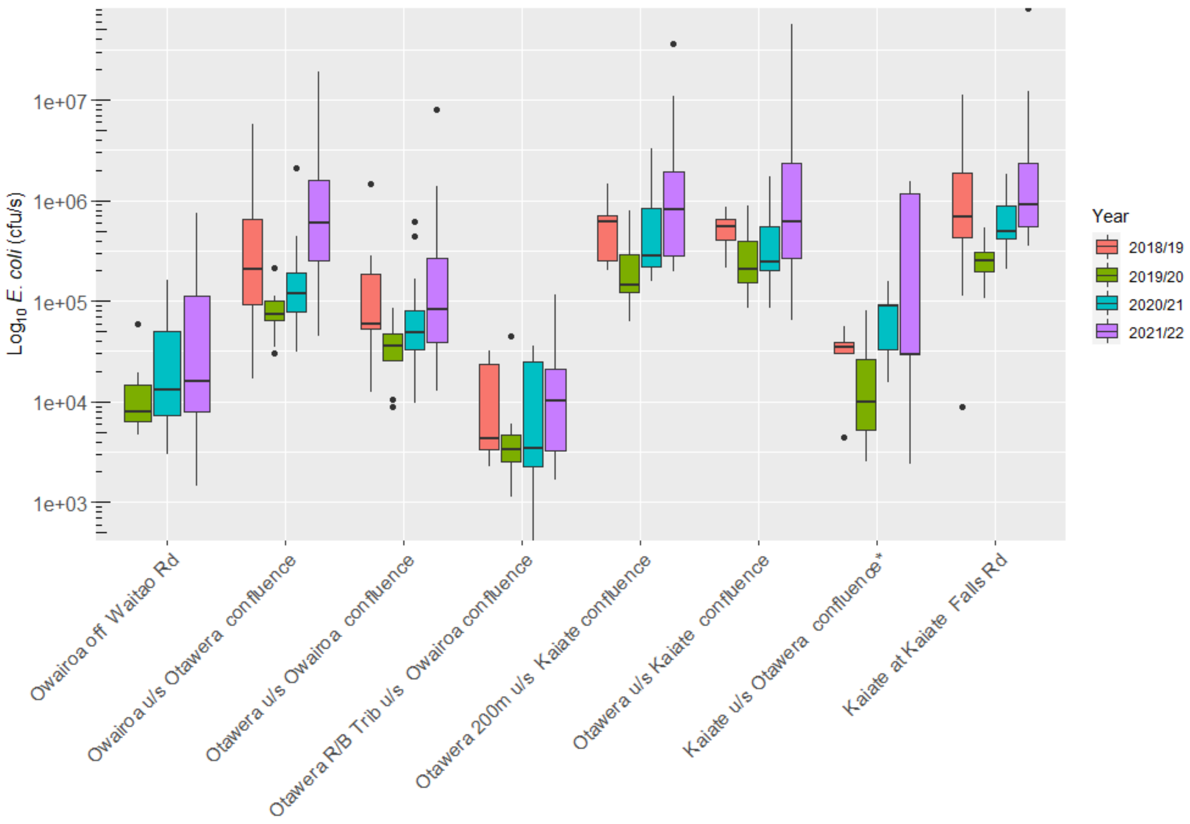

Figure 3-8 *E. coli load for all sites sampled over the 2018/2019, 2019/2020, 2020/2021 and 2021/2022 summers. Sites are arranged from upstream to downstream (left to right). Note log_{10} scale on y-axis. Site with asterisks (*) are sites where only actual gauging data has been used due to the lack of flow relationship with the Kaiate at Kaiate Falls Road site.*

3.6 Load Duration Curves

Figure 3-9 to Figure 3-13 show the LDC results for five sites (upstream to downstream); Owairoa off Waitao Road, Owairoa u/s Otawera confluence, Otawera u/s Owairoa confluence, Otawera u/s Kaiate confluence and Kaiate at Kaiate Falls Road. Note that the Kaiate u/s Otawera confluence (where a shift in the *E. coli* concentrations has been observed) does not have an LDC due to the lack of flow relationship needed to undertake this analysis.

These figures show that for at least part of the time, every site is exceeding the LDC of the 550 cfu/100 mL swimmability threshold. Under high flows and moist conditions, all sites exceed based on a 95^{th} percentile of the data. The results for the high flows and moist conditions should be interpreted with caution as samples have been collected during summer, where these flows are not as common (i.e., less sample points) and flow relationships are also based on summer flows. However, it is intuitive that *E. coli* would be high under high flow conditions with increased runoff and disturbance of the stream bed.

Under mid-range flows, all sites but Kaiate at Kaiate Falls Road are close to, or below the swimmability threshold, which could be a result of some dilution, but not enough energy in runoff to mobilise contaminants from land. Under dry and low flows *E. coli* increases above the threshold for the Otawera and Kaiate sites. The Owairoa is above the threshold in dry conditions and for part of the low flows. These results reconfirm a direct source as previously identified in Hudson (2019) and Zygadlo *et al.* (2021). The 2021/22 samples also make up part of the samples above the threshold, which rules out the 95th percentile being solely driven by previous years, before stock were removed from accessing the watercourses.

The Otawera u/s Owairoa confluence LDC shows this site to be exceeding the swimmability loading threshold under dry and low flow conditions more often than the Owairoa u/s Otawera confluence. This may indicate that the Otawera site is contributing a disproportionate amount of the loading compared to the Owairoa site under dry and low flows. However, as the Owairoa has a much larger flow compared to the Otawera u/s Owairoa, the majority of the bacterial loading is coming from the Owairoa. Overall, these results ultimately reinforce the results observed from load contributions presented in section 3.9 and Zygadlo *et al*., (2021).

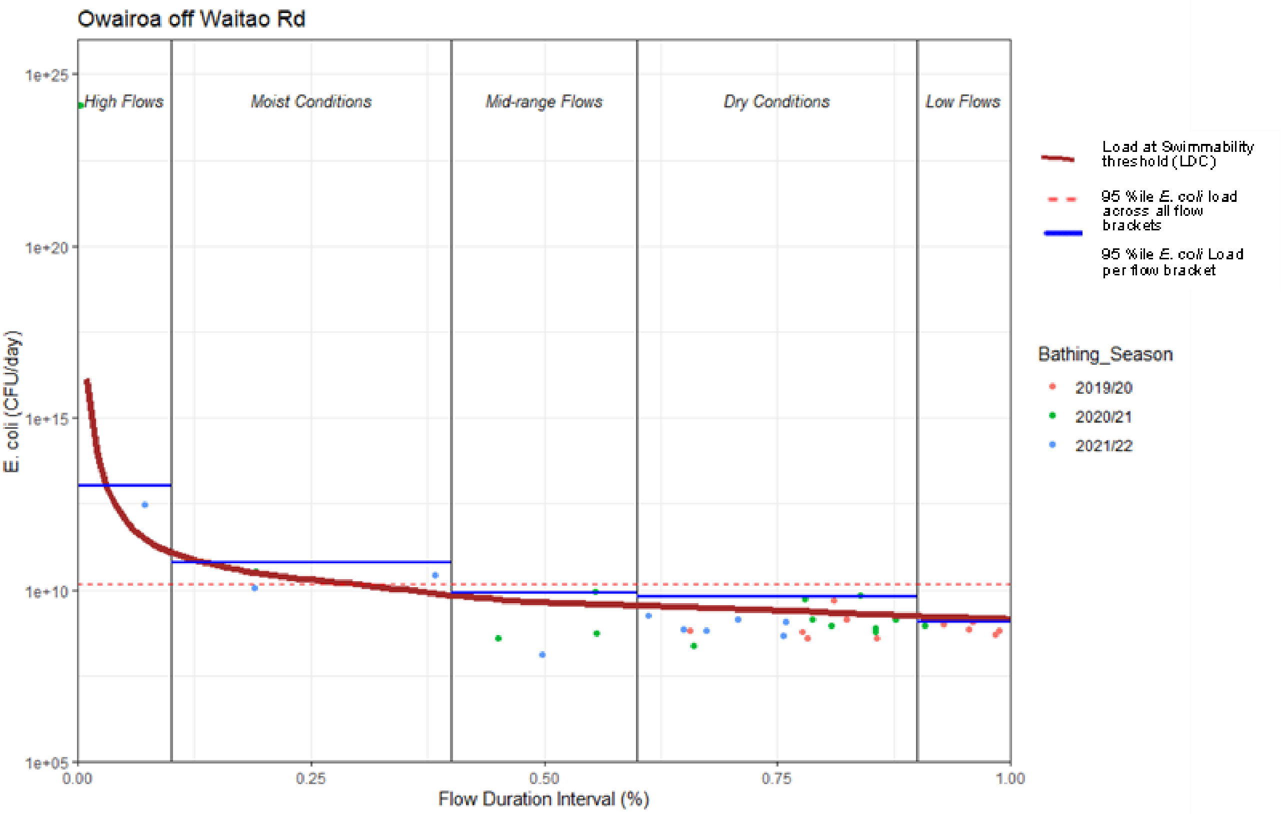

Figure 3-9 *Load Distribution Curve for Owairoa off Waitao Road site. Samples points from the 2019/2020, 2020/2021 and 2021/2022 seasons. Plot is split into flow brackets of high flows, moist conditions, mid-range flows, dry conditions and low flows. LDC is based off simulated continuous flow and 550 cfu/100 mL swimmability threshold.*

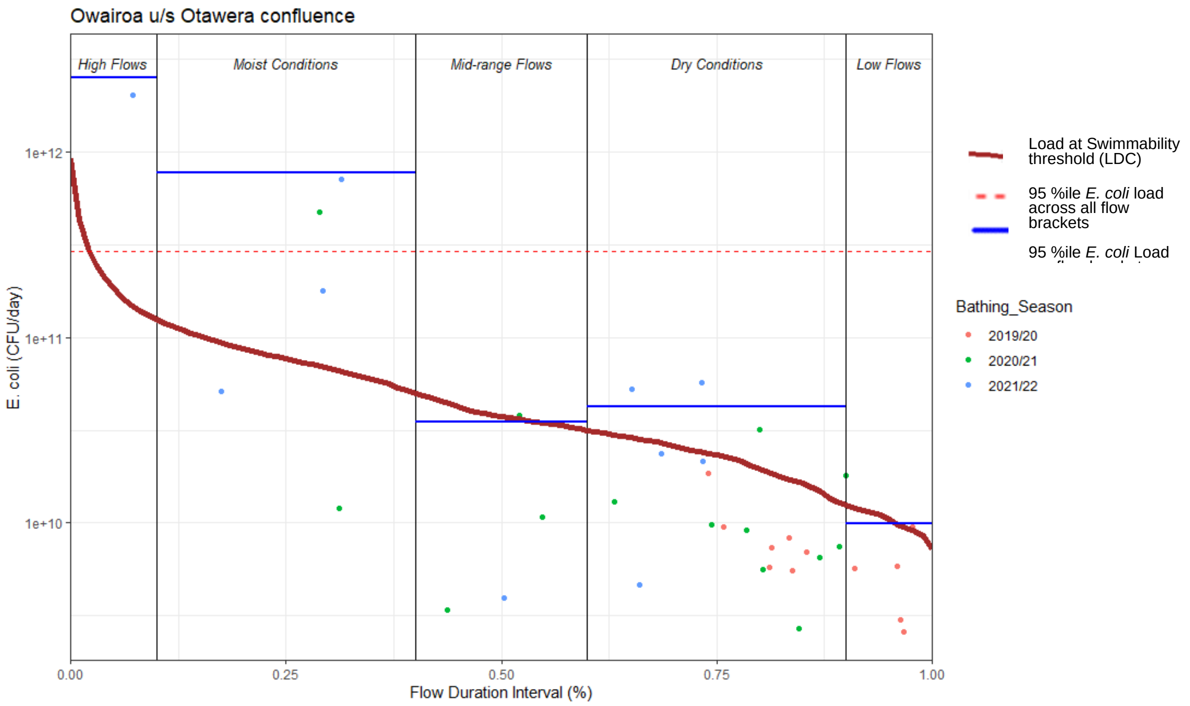

Figure 3-10 Load Distribution Curve for Owairoa u/s Otawera confluence site. Samples points from the 2019/2020, 2020/2021 and 2021/2022 seasons. Plot is split into flow brackets of high flows, moist conditions, mid-range flows, dry conditions and low flows. LDC is based off simulated continuous flow and 550 cfu/100 mL swimmability threshold

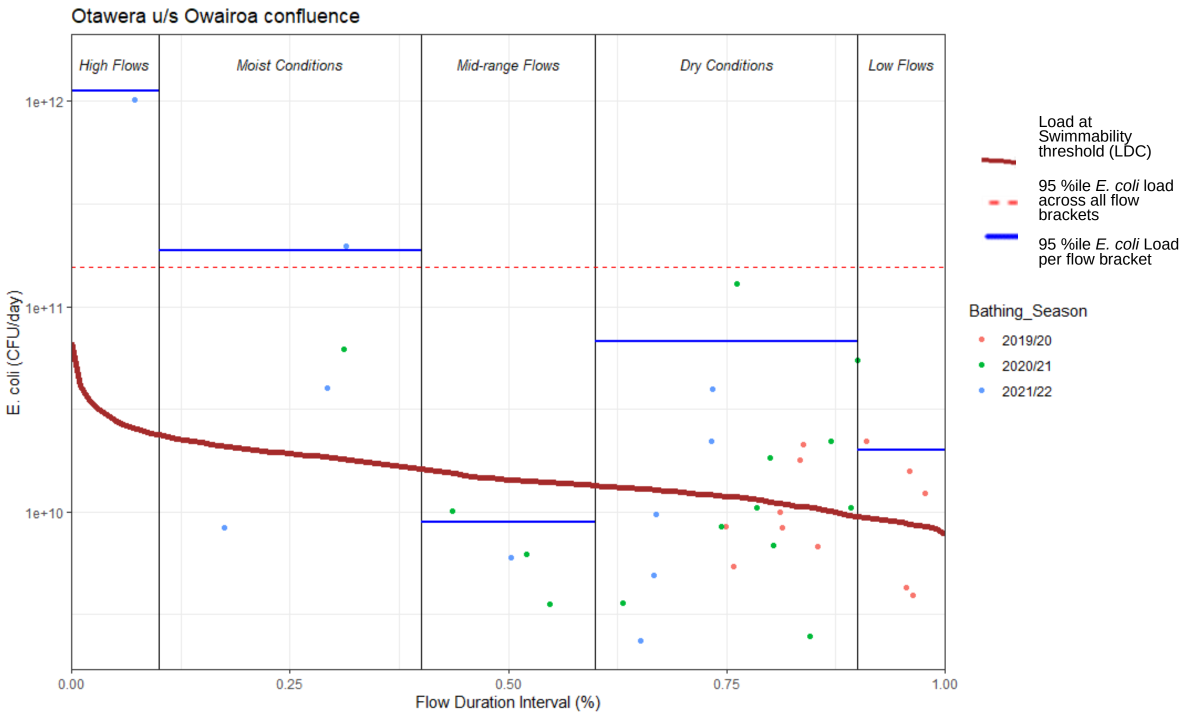

Figure 3-11 Load Distribution Curve for Otawera u/s Owairoa confluence site. Samples points from the 2019/2020, 2020/2021 and 2021/2022 seasons. Plot is split into flow brackets of high flows, moist conditions, mid-range flows, dry conditions and low flows. LDC is based off simulated continuous flow and 550 cfu/100 mL swimmability threshold

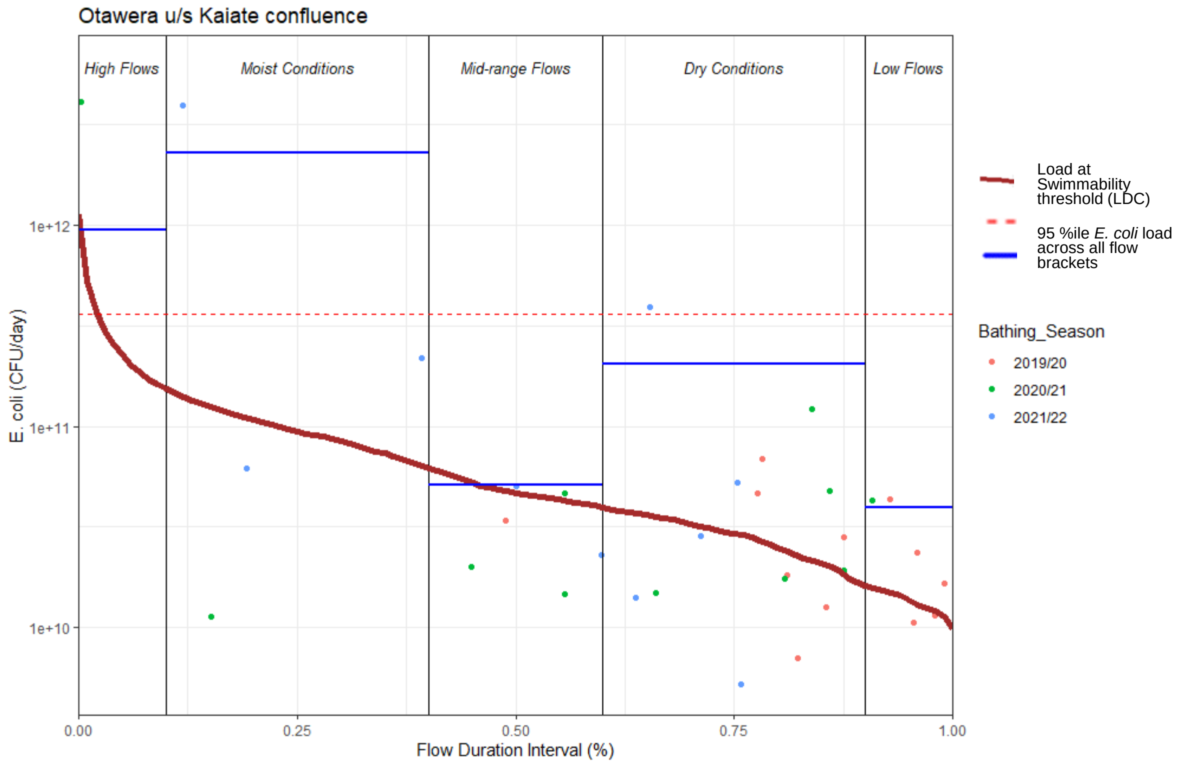

Figure 3-12 Load Distribution Curve for Otawera u/s Kaiate confluence site. Samples points from the 2019/2020, 2020/2021 and 2021/2022 seasons. Plot is split into flow brackets of high flows, moist conditions, mid-range flows, dry conditions and low flows. LDC is based off simulated continuous flow and 550 cfu/100 mL swimmability threshold

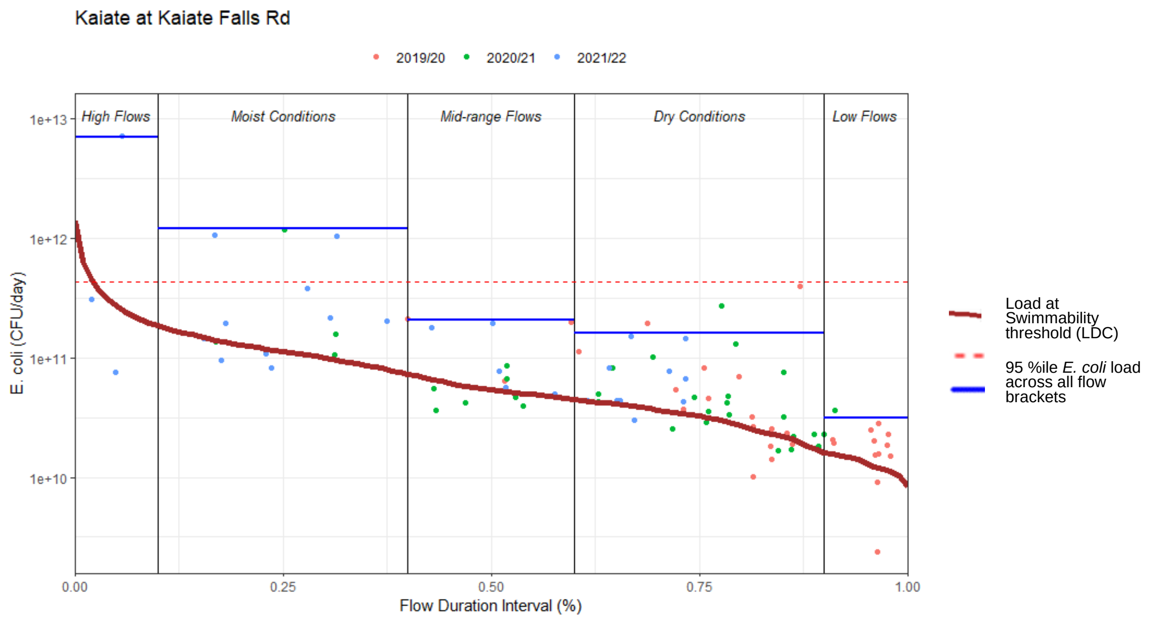

Figure 3-13 Load Distribution Curve for Kaiate at Kaiate Falls Road site. Samples points from the 2019/2020, 2020/2021 and 2021/2022 seasons. Plot is split into flow brackets of high flows, moist conditions, mid-range flows, dry conditions and low flows. LDC is based off simulated continuous flow and 550 cfu/100 mL swimmability threshold

3.7 QMRA and metagenomic ESR projects

Kaiate has been involved in on-going national projects. The first being a national Quantitative Microbial Risk Assessment (QMRA) to review the MWQG. These results are published as anonymous sites in ESR (2020) and ESR (2022). The analysis undertaken as part of this study showed that the Kaiate at Kaiate Falls Road site had levels of *Campylobacter*[3] considered high enough for human health risk, whereas the Owairoa off Waitao Road did not despite the sometimes-high *E. coli* levels observed there. This is an important piece of information as it is often asked whether there are actually pathogenic or disease-causing organisms within the river (given that *E. coli* is used as an indicator organism). This data confirms that there is a human health risk for recreational activity at Kaiate Falls.

The metagenomic work is a large study that will be some time before results are available for BOPRC to review.

[3] *Campylobacter* is often the target pathogen to base human health risk on as it is most frequently detected at concentrations high enough for infection risk (ESR, 2022).

4 Discussion (Matapakitanga)

The 2021/2022 data largely reinforces the findings of previous monitoring seasons. In this report, BOPRC have provided some additional analysis to explore any potential new perspectives to assist in managing the bacterial contamination. The discussion below is structured in relation to the aims identified in Section 1.2 and any new information.

4.1 Flow relationships (Aim 1)

The 2021/2022 sampling season provided some additional gaugings which altered the flow relationship for the Owairoa off Waitao Road site. This updated relationship did not change the overall results of the monitoring programme. As recommended in Zygadlo *et al*. (2021), should sampling be undertaken outside of the summer season, higher flow sampling should be coupled with gaugings to ensure the flow relationship to the rated site at Kaiate Falls Road remained appropriate. As the flow relationship was reasonably different from that reported in Zygadlo *et al.,* (2021), it would also be recommended that further gaugings are undertaken next sampling season at the Owairoa off Waitao Road site to further refine this relationship.

4.2 Otawera and Owairoa tributaries (Aim 2)

Bay of Plenty Regional Council understands that livestock in the native forest block (located around the site Owairoa u/s Otawera confluence) were removed before the summer monitoring programme for 2020/2021 began. Significant planting and fencing has also occurred resulting in all of the tributaries now excluding stock access, although some of this has occurred since monitoring concluded for the 2021/2022 season. I tis worth also noting that some critical source areas have not been retired.

A focus of this programme (both monitoring and land management) has been to remove the direct bacterial contamination inputs as results have consistently pointed to a strong baseflow signature of *E. coli* at the Kaiate at Kaiate Falls Road swimming site. The removal of stock from the bush block and significant fencing has not (yet) appeared to change that baseflow signature at the Owairoa, Otawera or Kaiate at Kaiate Falls Road monitoring sites. The Owairoa tributary is still contributing the largest load to the swimming site.

The LDC shows a different perspective where it investigates the time a site's loading is above the 550 cfu/100 mL swimmability guideline. This shows the Owairoa off Waitao Road to be below, or close to below, this threshold, whereas the Owairoa u/s Otawera and Otawera u/s Owairoa sites are often above that threshold. While loading contributions show the Owairoa u/s Otawera to be larger, the LDC suggests that the Otawera u/s Owairoa loading is above the swimmability threshold more often under dry and low flow conditions compared to the Owairoa u/s Otawera site. This could suggest that while the Owairoa tributary is contributing the largest load, the Otawera u/s Owairoa may be contributing a disproportionate amount of bacterial contamination downstream during low flows. Table 3 shows an estimate of flow and *E. coli* load contributions to the Kaiate at Kaiate Falls Road site. These are only estimates based off the data available at each site (i.e., does not take into account additional runoff or soakage etc). The Owairoa tributary contributes far more to the flow compared to the *E. coli* load, which may support the idea that the Otawera u/s Owairoa tributary contributing a disproportionate amount in comparison to the Owairoa u/s Otawera site. Regardless, contamination across both sites would need to be reduced to reduce the swimming site under the swimmability threshold.

Table 3 Average and median flow and E. coli load percentage contribution of Otawera u/s Owairoa confluence and Owairoa u/s Otawera confluence to the Kaiate at Kaiate Falls Road site. Note this is an estimate based off readings at each site and does not perfectly equal 100% of the Kaiate at Kaiate Falls Road site when all sites are considered.

	Flow		*E. coli* load	
	Otawera u/s Owairoa confluence	**Owairoa u/s Otawera confluence**	**Otawera u/s Owairoa confluence**	**Owairoa u/s Otawera confluence**
Mean	15%	71%	27%	47%
Median	14%	73%	10%	32%

4.3 Campylobacter

There are limited studies on the contribution of different species to *Campylobacter* levels in waters, however, Devane *et al.,* (2005) found no occurrence of *Campylobacter* in possum faeces and Pattis *et al.,* (2017) identified a median concentration two orders of a magnitude lower than what is found in bovine species (Moriarty *et al.,* 2008). The ESR results therefore might suggest that there is an input of faecal contamination downstream of the control (Owairoa off Waitao Road) site that contains *Campylobacter*. This is also in line with previous reporting of FST results (Mahon *et al*., 2020). Based on previous results and analysis, it has been suggested that there may be a large contribution of the bacterial loading from pest species in the bush block (Owairoa sites) and that significant pest management may be required to effectively reduce the bacterial contamination at the Kaiate at Kaiate Falls site. While this would still be the case, the combination of the information from the LDC and the ESR studies suggest that reduction in the Otawera tributary would both have significant effects on reducing bacterial contamination and also potentially *Campylobacter* concentrations. There are many unknowns, however, in relation to the *Campylobacter* contributions. An understanding of *Campylobacter* levels at Owairoa u/s Otawera and Otawera u/s Owairoa could provide more confidence around this.

It is also important to remember that the fencing and planting was only just completed during 2022. The value of additional information as suggested above may not be worthwhile until a couple or few seasons post land management efforts has occurred. It would be expected that flow related exceedances would continue to occur for many years, particularly as plants are still establishing. However, some improvement during dry and low flow conditions would be expected with the now full exclusion of stock from known flowing watercourses (some critical source areas and ephemeral flow paths are not fenced off) and particularly as the streams are largely hard-bottomed.

4.4 Kaiate u/s Otawera confluence (Aim 3)

The order of contribution to bacterial loading has largely remained the same over the monitoring seasons. The Otawera Sub-catchment is consistently the main contributor to the bacterial loading at Kaiate Falls. Changes within this sub-catchment are discussed above.

It was discussed in Zygadlo *et al.* (2021) that the Kaiate tributary contribution to Kaiate Falls had increased compared to the previous seasons. At that stage, significant fencing had occurred upstream of this area, however, one area was yet to be fenced. Given that livestock were currently grazed in this area, it was reasonable to expect some concentration of the livestock in the unfenced area which may have explained the increase in loading. This tributary was fully fenced and planted before the 2021/2022 sampling season began. Results from this season showed some much lower concentrations and hence loading during dry weather. However, there are still occurrences of high concentrations, resulting in a large range for this site. This tributary is particularly boggy and wetland like. It would be reasonable to conclude that the exclusion of stock from this area is the cause of intermittent reductions of bacterial loading. The wetland-like nature of the area means that when there is any disturbance (e.g., bird activity, rain), it can re-suspend the deposited sediment and bacteria with it. This may explain the couple of higher concentrations observed during dry weather. It is also worth noting that the wetland like environment may be attracting more birds, which could also increase bacteria concentrations. It would be expected that high concentrations would still be observed during rain events, particularly as the planting would not have had time to establish and assist in filtering runoff through the system.

5 Recommendations (Ngā Tūtohutanga)

Partner with local iwi on communications and pest management in bush block

Initial progress was made since Zygadlo *et al.,* (2021) on an updated fact sheet for iwi and community. This should be progressed with potentially updating the warning sign at the swimming site with an information board. The public would greatly benefit from knowing that pathogens such as *Campylobacter* are being detected here.

Furthermore, it has been suggested previously that an updated pest management survey was undertaken in the bush block. This would help understand levels of pests and their potential contribution to bacterial contamination within the catchment. Pest management should be prioritised as this sub-catchment continuously shows to be the largest contributor of load to the swim site.

Ongoing monitoring

Monitoring should continue to record changes as a result of the mitigation actions taking place. Future monitoring will need to include flow measurements at Kaiate u/s Otawera confluence due to the lack of flow relationship found at this site. Owairoa off Waitao Road should also have additional gaugings to further develop that flow relationship.

Investigate upper catchment results from MfE and ESR

Funding has been confirmed for ongoing monitoring within the Kaiate catchment for the QMRA project. This is information that BOPRC would not otherwise have access to and should continue to inform future monitoring and mitigation efforts.

Investigate contribution of climatic factors to observed results

It would be interesting to understand the potential contribution of climatic cycles on the results at this site and whether it may explain some of the degradation apparent in Figure 3-1. This is not a simple process to undertake but could be investigated in the future.

6 Conclusion (Whakakapinga)

Kaiate Falls has had a permanent public health warning in place since 2015. Research in the Kaiate Falls Catchment has been undertaken since 2015 to identify the source of bacterial contamination and inform actions, to ultimately improve water quality enough to allow the health warning to be lifted.

The major contribution is still from the Otawera Sub-catchment. The decrease at the Kaiate tributary emphasises the importance of fencing off all waterways to make a measurable improvement. While no overall improvement has been observed, monitoring should continue as fencing and planting is now complete.

7 References (Ngā Tohutoro)

ANZECC & ARMCANZ. (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. https://www.waterquality.gov.au/anz-guidelines/guideline-values/default

Hudson, N. (2019). Review of Faecal Indicator Bacteria Contaminant Loads – Kaiate Stream, Tauranga Harbour Catchment. NIWA report for Bay of Plenty Regional Council, June 2019. Hamilton, New Zealand.

ESR (2020) Quantitative Microbial Risk Assessment Pilot Study. Report prepared for Ministry for the Environment. Client Report No: FW20007

ESR (2022) Quantitative microbial assessment: Phase 2.1 – Initial data collection and recommendations. Report prepared for Ministry for the Environment. Client Report No: FW21019

Mahon, L., Zygadlo, M., Carter, R., Crawshaw, J., & Dare, J. (2020). Focus Catchments Water Quality 2020/Te Kounga Wai O Ngā Kurawai E Arotahia Ana. Bay of Plenty Regional Council Environmental Publication 2020/04.

Ministry for the Environment. (2003). Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Publication reference number ME474.

Ministry for the Environment. (2020). National Policy Statement for Freshwater Management 2020. Wellington, New Zealand. National Environmental Monitoring Standards. (2013). Open Channel Flow Measurement. National Environmental Monitoring Standards, New Zealand.

United State Environmental Protection Agency. (2007) An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006.

Zygadlo, M., Mahon, L., Carter, R. (2021) Focus Catchments Water Quality Update 2021. Bay of Plenty Regional Council Environmental Publication 2021/10.