MEMORANDUM

To:	James Low/ Nicola Green **Team Leader/Senior Planner (Water Policy)**	
From:	Paul Scholes **Team Leader Science**	**Date:** 15 November 2018
File Ref:	A3041213	
Subject:	**Estimating bacterial load reductions to Maketū and Waihī estuaries**	

1 Introduction

As required by the National Policy Statement for Freshwater Management (NPS-FM), Bay of Plenty Regional Council must implement freshwater objectives, limits and methods for achieving agreed sustainable management of freshwater quality and quantity in the region. BOPRC has divided the task up into Water Management Areas (WMAs) comprising defined individual surface water catchments and has commenced the NPS-FM implementation process on the Rangitāiki and Kaituna-Pongakawa-Waitahanui WMAs. The NPS-FM requires Councils to have regard to the connections between freshwater bodies and coastal water, and seeks to improve integrated management of freshwater and land in whole catchments, including interactions with the coastal environment. Amendments made in 2017 strengthened this direction.

For Waihī and Maketū Estuaries, earlier reports documented sensitivity to catchment inflows and the extent to which ecological health has been impacted (Hamill 2014, Park 2016). This was later updated in 2018 and sensitivity to catchment inflows was assessed using the ETI Tool 1. Both Maketū and Waihī Estuaries are in poor ecological condition with the highest stressor for both estuaries being eutrophication. Assessment of susceptibility to eutrophication placed Maketū Estuary at high risk and Waihī Estuary at very high risk of degradation as a result of the current nutrient loads (Hamill 2018).

The Regional Coastal Environment Plan (RCEP) identifies the significant cultural values of the Waihī and Maketū estuaries, particularly for mahinga kai gathering and spiritual reasons. In addition, it sets policy direction that discharges in to estuaries should meet water quality classification standards (after reasonable mixing) as follows, which assumes the standard is met in ambient conditions / prior to any new discharge:

- Estuaries are safe for primary contact recreation/bathing: The concentration of enterococci must not exceed 280 cfu/100ml. See Microbiological Water Quality Guidelines for methodology.

- Kaimoana are safe to eat: The median faecal coliform content of water 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 (using a five-tube decimal dilution test).

Reduction of pathogens entering the estuaries from freshwater inputs may be required if the recreational values of Maketū and Waihī estuaries are to be enhanced.

Indicator bacteria used for swimming and shellfish water quality are good indicators as they provide a useful management tool to assess the risk to human health, and as an indicator of faecal contamination. There are at least two concerns for ensuring sufficiently low bacterial concentrations:

- Protection of people swimming in water or coming into contact with water from other recreational activities (e.g. boating), because there is a risk of consuming water during these activities; and

- Protection of people collecting and consuming shellfish because there is a risk of ingesting pathogens if critical bacteria levels are present in shellfish.

This memorandum examines the microbiological state of Waihī and Maketū estuaries with respect to current water quality guidelines. Current and past state data along with recent modelling is used to estimate the reduction of faecal indicator bacteria (FIBs) required within the estuaries to meet the values in the RCEP. Estimates of the reduction required from freshwater bodies discharging into the estuaries to meet the water quality classifications mentioned above are also presented.

No detailed examination of where FIBs are coming from in the landscape (sources) is undertaken, although some catchment results are presented where information was available. Further work on catchment sources will be required to help prioritise and target mitigation and planning measures.

2 Current State of Microbiological Water Quality

Recreational values associated with swimming and shellfish collection are primarily restricted to the bottom end of the estuaries, nearer the estuary outlet, where water is deeper and more influenced by mixing with oceanic waters. This is also where the more abundant shellfish beds are located (Gaborit-Haverkort 2012). Hence this area of the estuaries is the focus of targeting any bacterial loading limit to the estuary with the aim of lessening the risk of infection to swimmers and consumers of shellfish.

Generally swimming water quality is good at monitored sites in the lower estuaries, but swimming water quality is at times compromised, with 95th percentile results being over the Microbiological Water Quality Marine and Freshwater guidelines orange alert level.

Swimming water quality at the current monitoring location in Maketū estuary is consistently good and the aim would be to maintain this quality (Figure 2.1). Waihi estuary water has less tidal dilution than Maketū (Appendix, Table 6.2), which may be one reason for the poorer bacterial quality (Figure 2.1). Last seasons' results for the monitoring location in Waihī estuary showed that indicator bacteria were above the orange alert level for 5% of the season.

Shellfish water quality is also guided by the Microbiological Water Quality Marine and Freshwater Guidelines (2003). Water samples from monitored sites are analysed for Faecal Coliforms (FC), which are suitable microbiological indicators for sanitary safety in regard to shellfish consumption. Faecal coliforms have a stronger correlation with health risks associated with eating shellfish than enterococci (MfE/MoH, 2003), making them a useful indicator. The FC values specified in the microbiological guidelines indicate the likely presence of pathogenic bacteria, protozoa and viruses. The guidelines for safe shellfish consumption are as follows:

- The median FC content should not exceed a Most Probable Number (MPN) of 14/100 ml, and
- No more than 10% of samples should exceed a MPN of 43/100 ml.

Note that compliance with these guidelines does not ensure that shellfish in the waters will be safe for consumption as they do not account for bio-toxins.

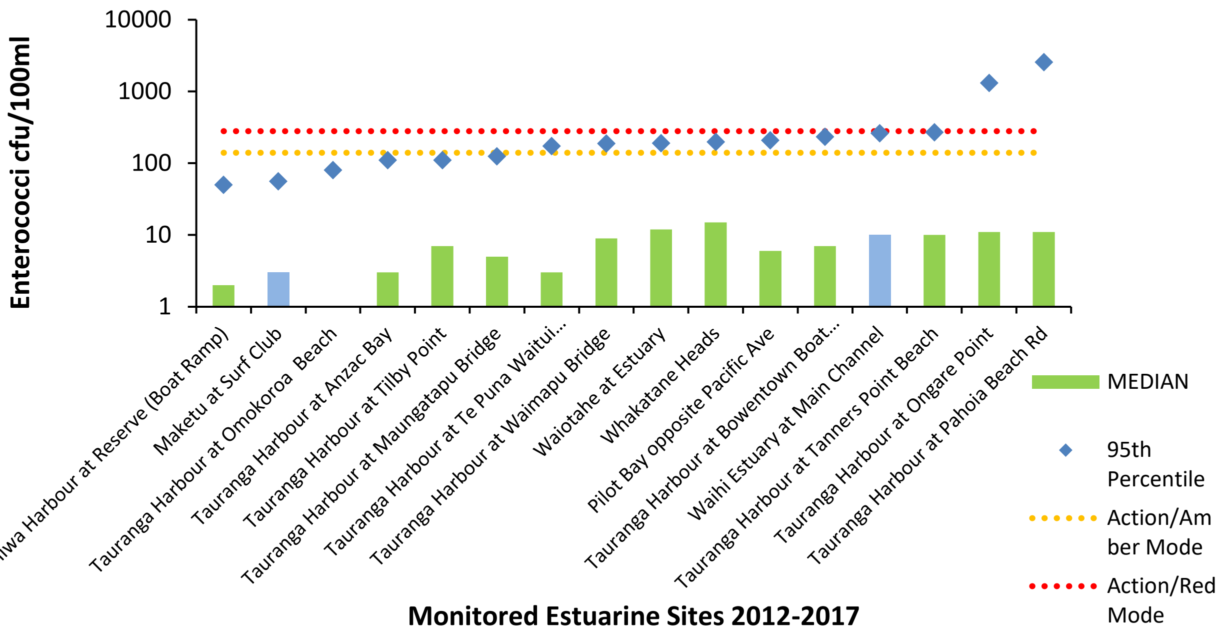
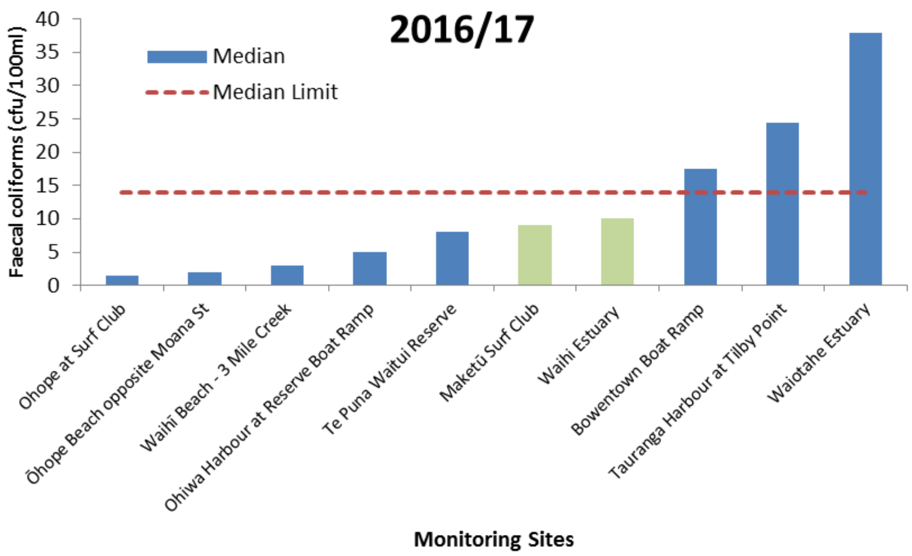


Figure 2.1: 95th percentile and median results for enterococci concentrations at Bay of Plenty estuarine marine sites over 2012 to 2017. Maketū & Waihī estuaries are highlighted in blue.

Figure 2.2 and 2.3 show the results of faecal coliform monitoring in Waihi and Maketū estuaries over the 2016/17 and 2017/18 seasons. Maketū Estuary met the median threshold (14 FC/100ml), but Waihī Estuary has not for the last season (2017/18). Both sites have not met the threshold of 43 faecal coliforms/100ml for 90% of the time for the last two seasons. Hence, there is a health advisory not to take shellfish from Waihī Estuary, but no advisory for Maketū Estuary as both thresholds have not been triggered.



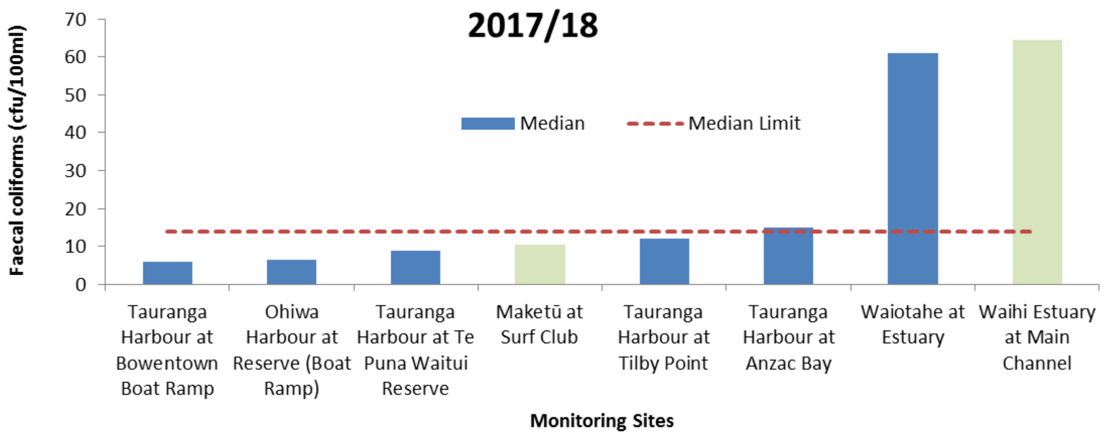


Figure 2.2: Median faecal coliform concentrations at shellfish gathering locations for the 2016/2017 & 2017/2018 seasons and guideline median limit for safe shellfish consumption.

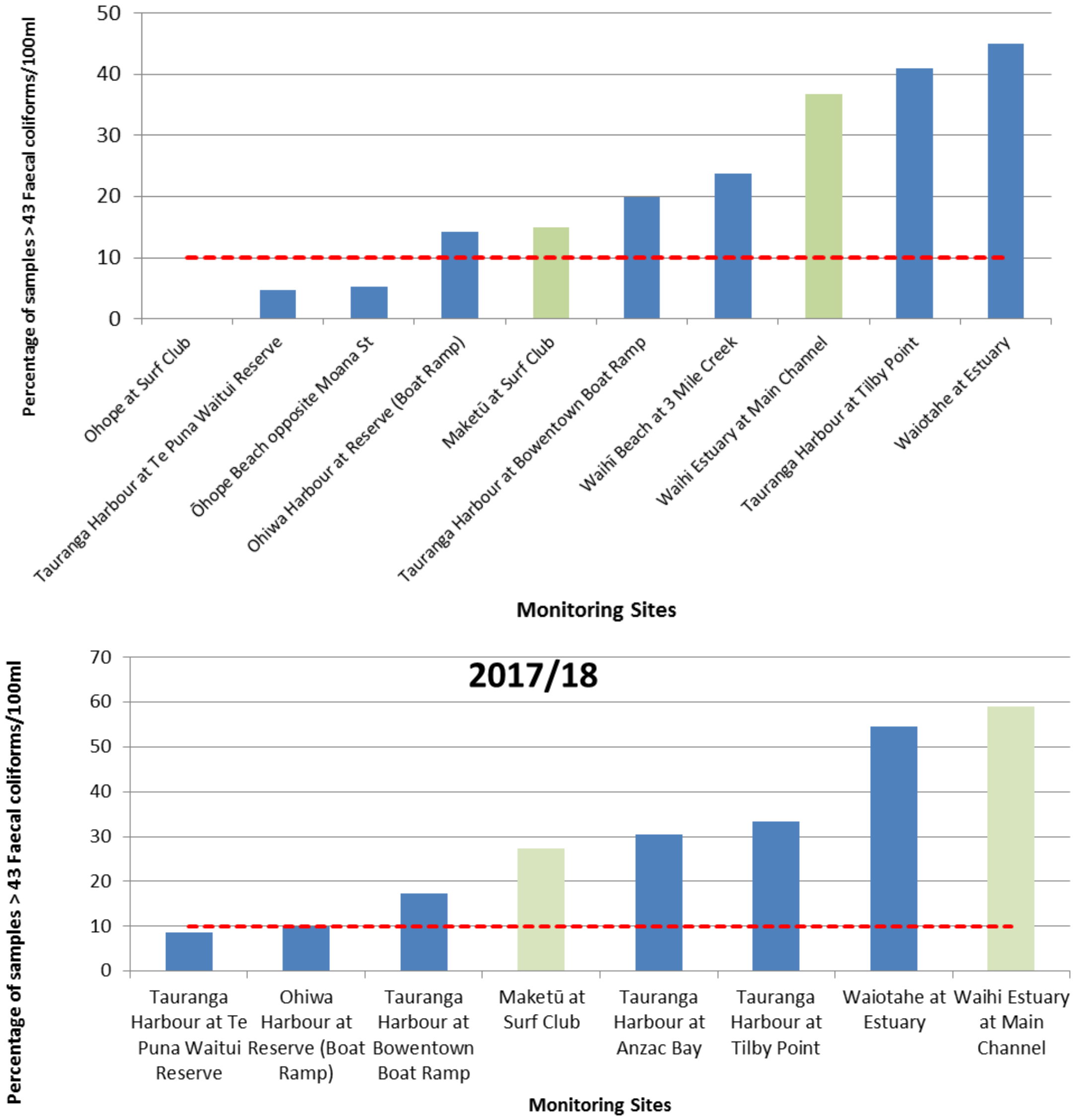


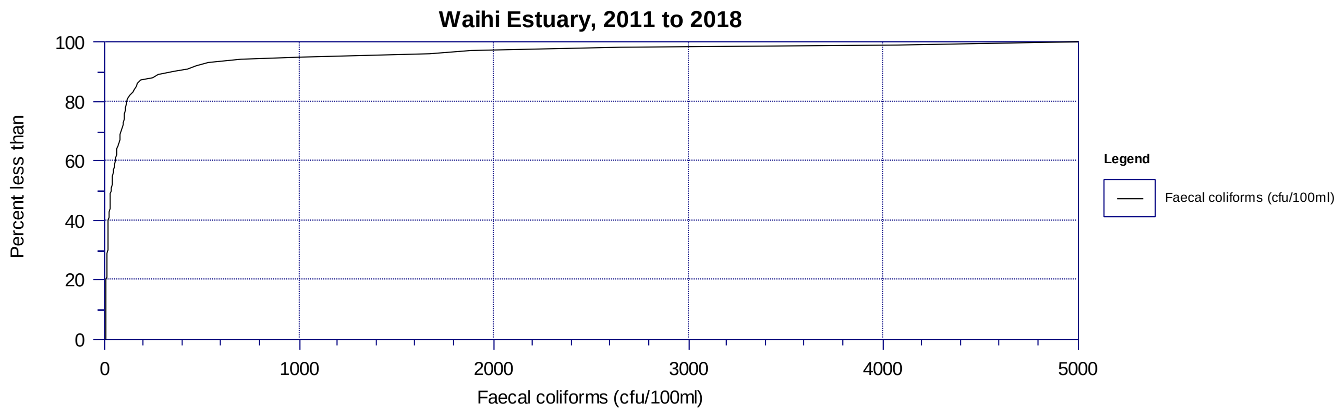
Figure 2.3: Percentage of samples at shellfish gathering locations in the 2016/2017 & 2017/2018 seasons exceeding the faecal coliform limit of 43 cfu/100 ml stipulated by the Microbiological Water Quality Guidelines (MfE/MoH 2003) for marine sites.

3 Faecal Indicator Bacteria Reduction Targets for Shellfish Consumption

3.1 Waihī Estuary

Reduction of the faecal bacteria loading contributing to shellfish contamination would be required to meet the estuary water quality standards in the RCEP. Based on the data distribution the aim would be to decrease the amount of time the water exceeds 43 faecal coliforms/100ml. Reducing the influx of faecal indicator bacteria (FIBs) from freshwater inflows will also improve swimming water quality.

The longer term faecal coliform data set indicates that the 43 n/100ml threshold is exceeded 36% of the time (Figure 3.1) compared to just over 40% of the time for the last seven years (based on the best available data).



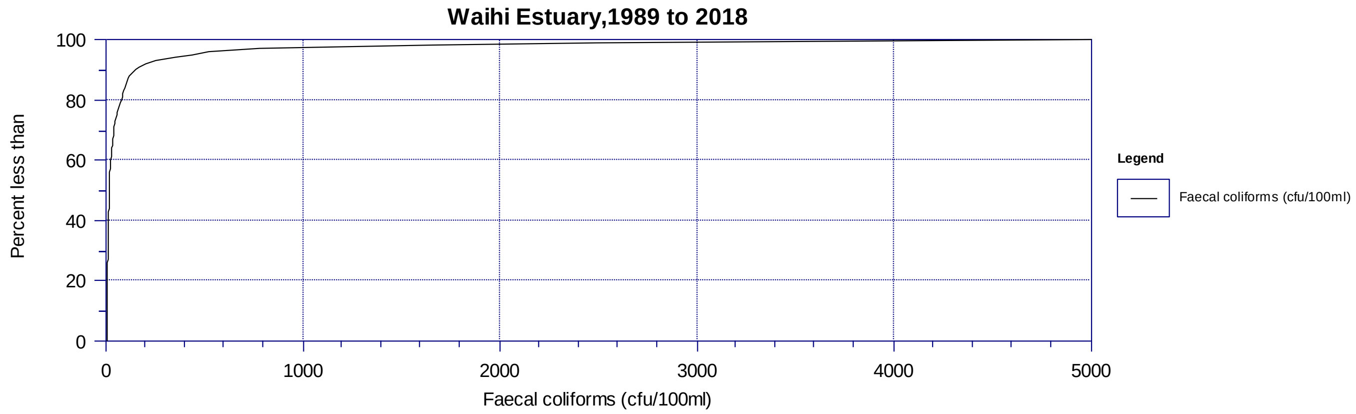


Figure 3.1: Frequency distribution for faecal coliforms in Waihi estuary water - 2011 to 2018.

To determine the level of reduction in faecal coliform bacteria required to reach the water quality objective of "*no more than 10% of samples should exceed a MPN of 43/100 ml"*, the change in concentration required to reach this target was modelled against the last seven years of faecal coliforms results from the estuary. The model assumes a direct proportional reduction is required.

This analysis shows that a reduction in faecal coliform concentration of greater than 80 percent would be required (Figure 3.2). Note that enterococci and faecal coliform have a reasonably linear relationship, as do *E.coli* and faecal coliforms (see Figure A1, Appendix1). The relationship between these faecal indicators shows that reduction in one will achieve similar results in others.

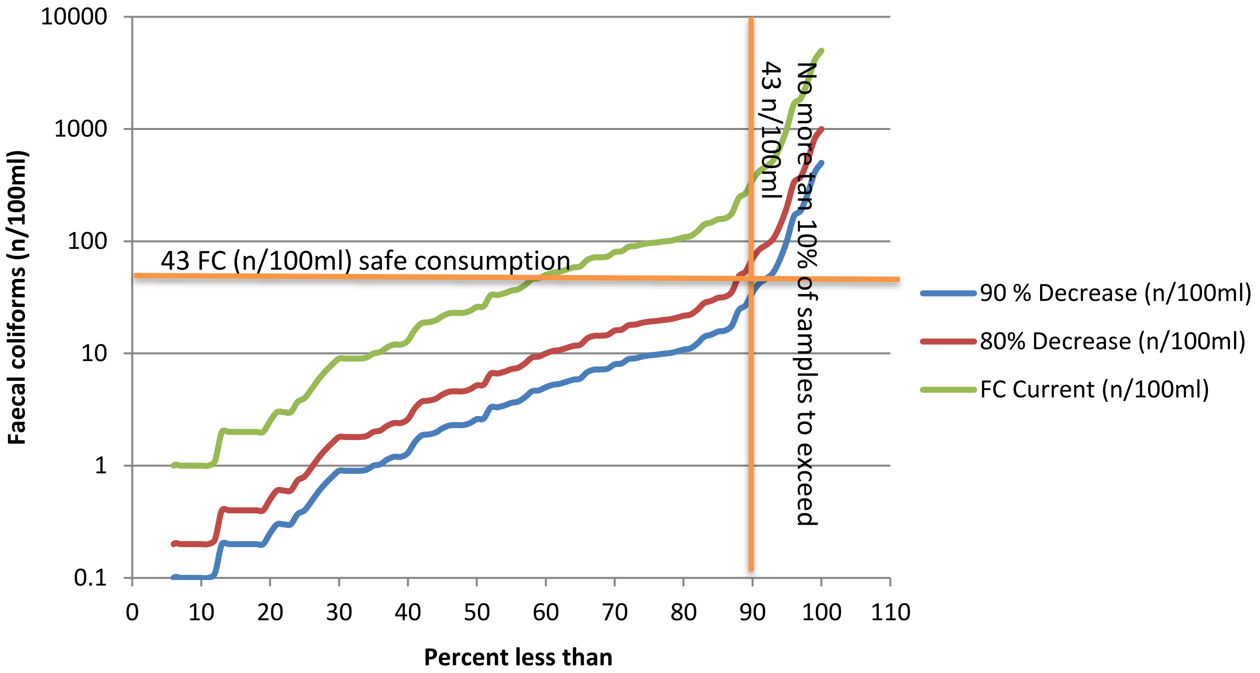


Figure 3.2: Projected change in faecal coliform concentrations from current (2011-18) to reach the objective of "no more than 10% of samples exceeding 43/100 ml".

3.1.1 Faecal contamination in freshwater entering the estuary

The main inflows to the Waihī Estuary are the Pukehina, Pongakawa, Wharere (including tributaries, the Wharere and Puanene streams), and Kaikokopu canals (Figure 3.3).

The direct relationship between freshwater flow (as measured at Pongakawa SH2) and FIBs in the estuary is weak, and may reflect the lack of comparable data (taken on the same day under similar conditions). Also tidal re-suspension and other decay mechanisms complicate the relationship. Seasonality of freshwater inputs is not strong, peaking in winter.

There is limited FIB and other water quality data for the four major inflows into the estuary and this is restricted mostly to the period 2014 to 2016. Flow data is lacking from this data set, and gaps have been supplement by SOURCE hydrological modelling data (Loft et al., 2018).

A linear relationship was assumed between loads and concentrations to convert load (from freshwater inflows) into concentration (in the estuary). Hence, the assumption will be that a mitigation action that reduces loads from freshwater inflows by a certain percentage, will achieve the same relative bacterial reductions in the estuary. The linear relationship has been tested in the freshwater inflows (Figure 3.4) with recent *E. coli* concentration data to the estuary and flow data (based on SOURCE modelled flow).

Estuary dilution factors averaged over a tidal cycle (see Table 3.1) have been used to calculate indicator bacteria concentrations. No factoring of decay or deposition is accounted for. The relationship between inflow load and estuary concentration can be used to estimate a load that is equivalent to the shellfish water target of 43 n/100ml concentration (assuming a 1:1 *E. coli*: Faecal coliform relationship). Using this relationship (Figure 3.4) we can estimate the inflow *E. coli* load to the estuary needed to achieve the shellfish water threshold of 43 n/100ml faecal coliform concentration. The estimated load to meet this target is <u>9×10^{11} coliform units (cfu) per day.</u>

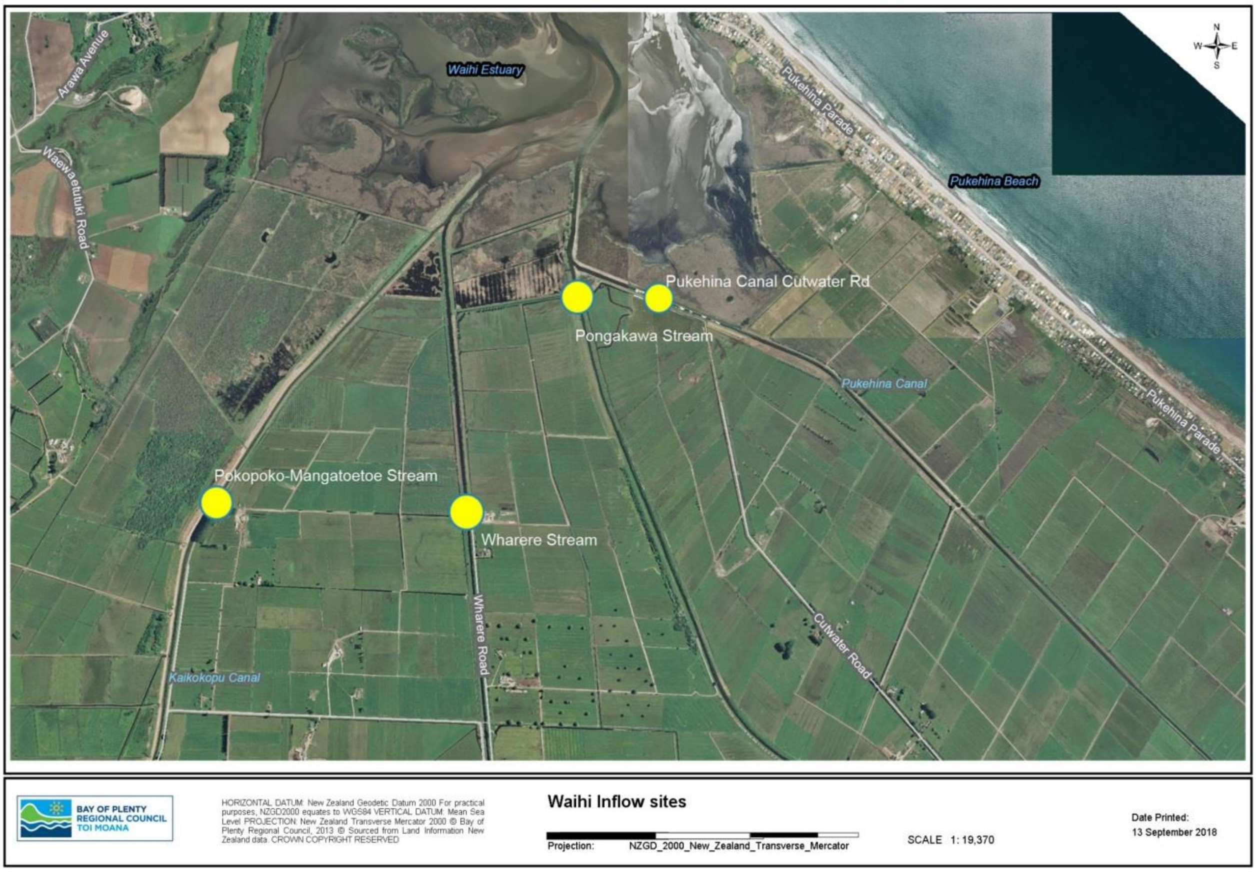


Figure 3.3: Waihī Estuary stream inflow sampling locations.

Table 3.1: Tidal volume changes and estimated dilution of freshwater inflows into Waihī Estuary.

Hour	Hourly tidal volumes (m^3)	Dilution factor	Average Hourly dilution
0	246,000	0.0000	
1	393,000	0.0966	0.0483
2	786,000	0.0483	0.0725
3	1,179,000	0.0322	0.0403
4	1,572,000	0.0242	0.0282
5	1,965,000	0.0193	0.0217
6	2,358,000	0.0161	0.0177
		Average dilution over a tidal cycle	**0.0381**

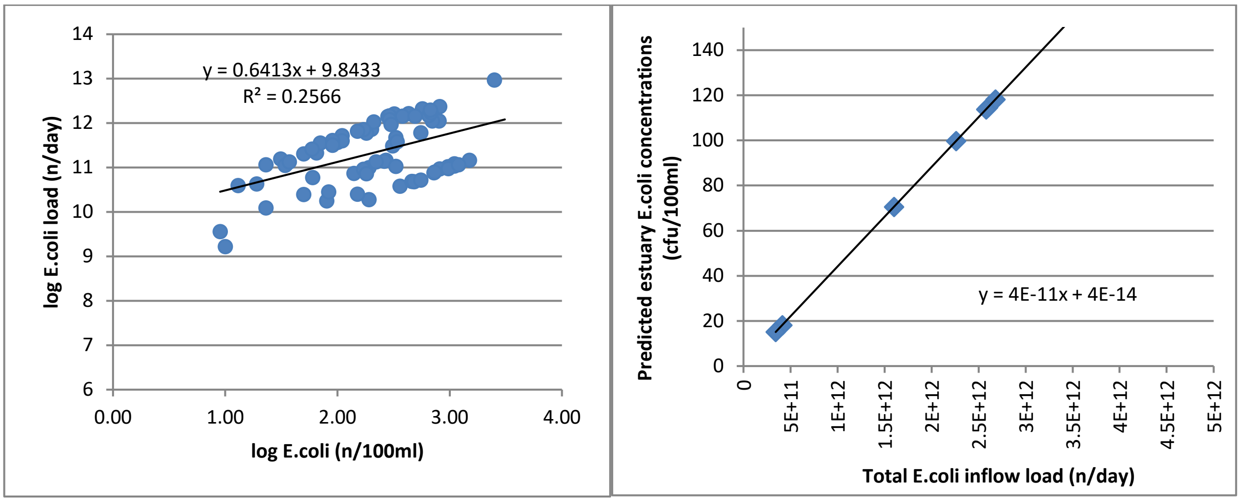


Figure 3.4 Left - *E.coli* concentrations versus *E. coli* load from four inflows to Waihī estuary 2014 to 2016 (left); Right - the relationship between predicted average *E.coli* concentrations based on estuarine dilution vs daily *E. coli* inflow loads.

Plotting modelled inflow *E.coli* loads and the observed estuary *E.coli* concentrations shows the reductions that might be required to achieve faecal coliform concentrations in the estuary to consistently meet the Microbiological Water Quality Guidelines (MfE 20003) for safe shellfish consumption (Figure 3.5). A frequency distribution of the modelled *E.coli* load to the estuary shows that the <u>$9x10^{11}$ coliform units (cfu) per day</u> is exceeded around 46 % of the distribution (Figure 3.6). While the reduction in faecal indicator concentrations in the estuary needed to reach the guideline criteria is upwards of 80%, the actual inflow faecal contamination load (as measured by *E.coli*) would need to be reduced by less than 50%. The portion of loads that would achieve the most reduction typically occurs under higher flow conditions - that is during rainfall generated run-off.

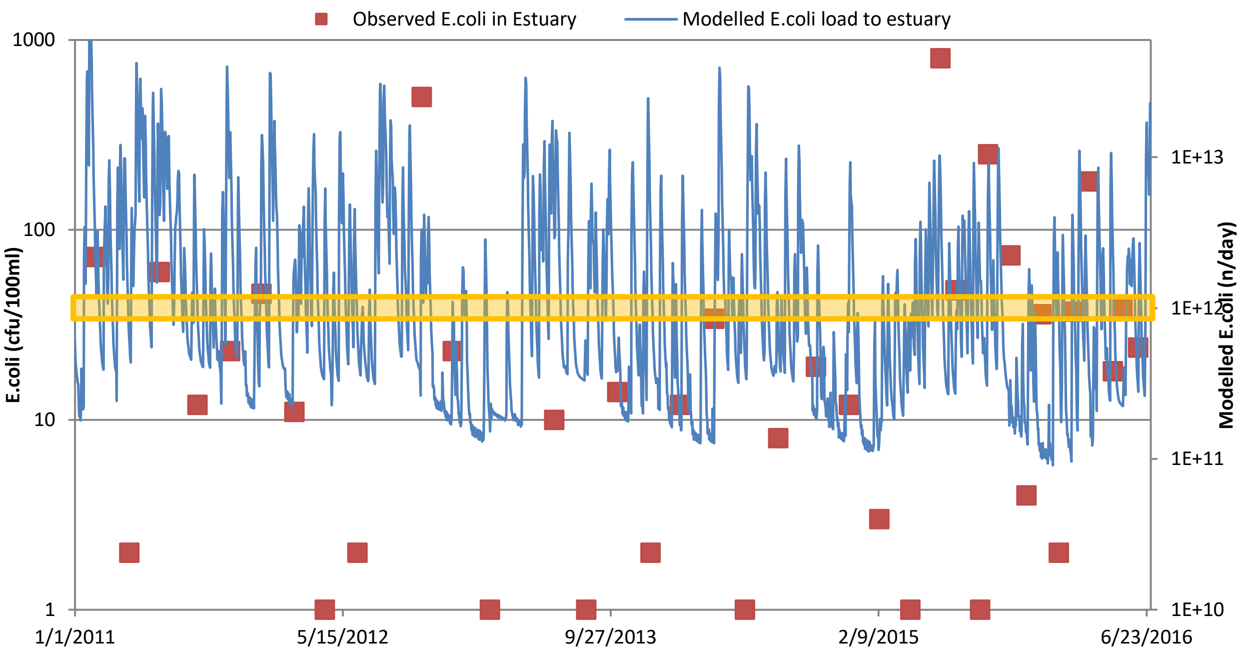


Figure 3.5 Modelled inflow *E.coli* loads into Waihī estuary (ESource model run April 2018) and estuary *E.coli* concentrations, 2011 to 2016. Above the orange area are loads that would trigger the shellfish water microbiological guideline concentration of 43 faecal coliforms (*E.coli*)/100ml.

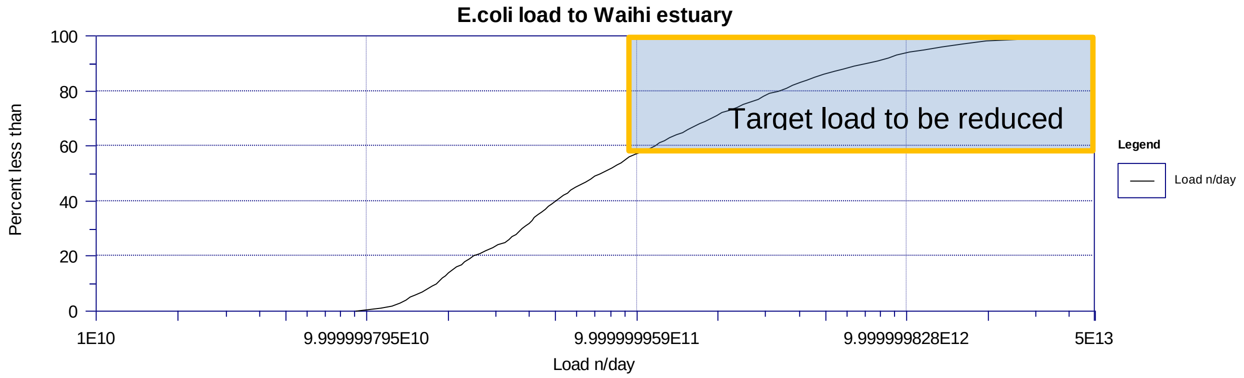


Figure 3.6: Frequency distribution of modelled *E. coli* load from inflow sources to Waihī Estuary, 2011 to 2016.

The percentage reduction required for faecal loads from freshwater inflows may be even lower, as the *E. coli* results from the SOURCE model tends to predict lower concentrations (*E. coli* <10) poorly. Improvement in the SOURCE model to better distribute the first order of magnitude range would change the distribution of concentration data, which would reduce the percentage reduction required. Alternatively comparison of measured data with the modelled could be undertaken only at concentrations above the first order data.

Also not taken into consideration in this estimate of inflow loading and estuary bacterial concentrations is the decay of the bacteria on entry to the estuary. Decay is dependent on a range of factors (salinity, temperature, light, predation, dilution, seasonality), with k-values for *E. coli* and also the k-values for enterococci being regarded as in the same order of magnitude (Hijnen et al, 2007). On balance, changes to decay rates on entry to the estuary will be offset by dilution changes and we might assume that loading reduction due to decay will not greatly impact the scale of inflow loading required to reduce faecal coliform levels to below the shellfish waters guideline.

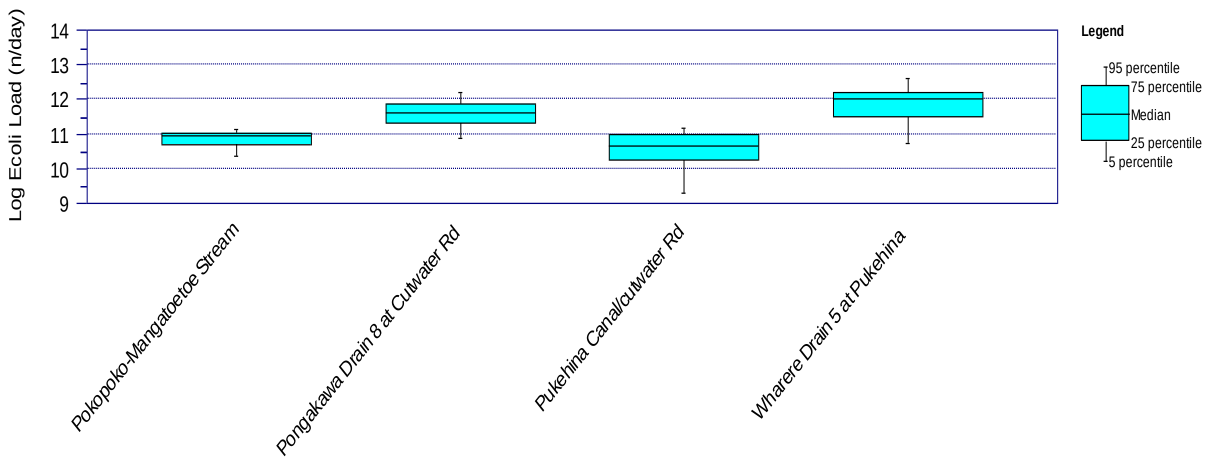


Figure 3.7: *E. coli* load from Waihī Estuary inflows based on modelled flow data and measured *E.coli* concentrations 2014 to 2016. Note log scale.

Modelling results and estimated loading figures will be useful in targeting where and what remediation measures might be employed to bring about a reduction in faecal contaminant loading. Figure 3.8 shows the 95 percentile *E. coli* concentrations over the modelled sub-catchment (along with the observed 95 percentile) and reveals where the higher event load concentrations are coming from. Estimated *E. coli* loads from the four stream inputs also show where the majority of loading comes from (Figure 3.7), and this information can be used to inform strategies for reducing faecal contamination.

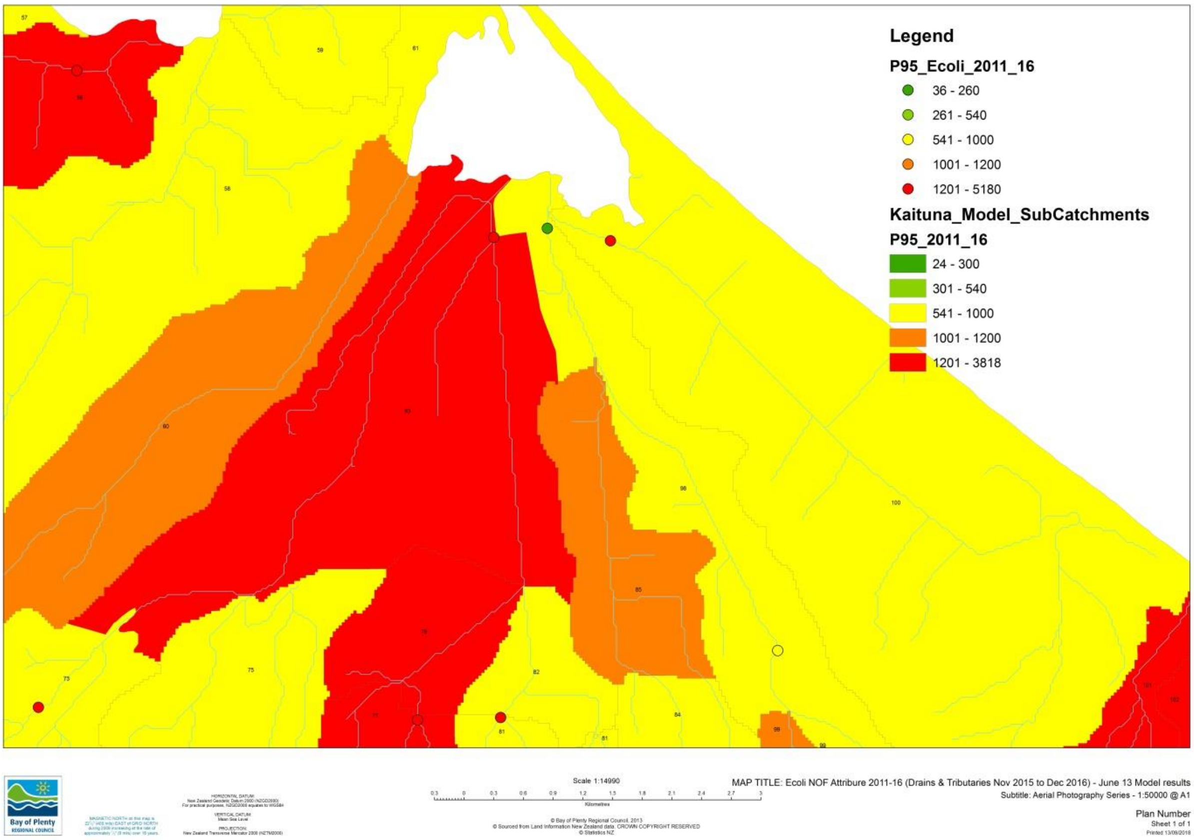


Figure 3.8: Shaded circles indicate *E. coli* data (95th percentile) for drains (2015/16 data) and SOE water quality sites (2011-16 data), shaded sub-catchments show SOURCE model predictions.

3.2 Maketū Estuary

Monitoring of water quality in Maketū Estuary has shown that the shellfish guideline of 43 faecal coliforms/100 ml has been exceeded for around 26% of results (Figure 3.9). This longer sequence of data also shows that faecal coliform results have remained under the median guideline value of 14 faecal coliform per 100ml (Table 3.2). As both conditions need to be exceeded to trigger exceedance of the guidelines (see Section 1), no health warning has yet been issued for the estuary. As one of the shellfish water threshold is being exceeded in one case, and near to be exceeded in the other, further exploration of the risk to shellfish gatherers is warranted.

Table 3.2: Faecal coliform concentration statistics from the Maketū Estuary Boat Ramp site and Surf Club sites, 2015 to 2018.

Variable	Sample size	Minimum	Maximum	Mean	Median	95 percentile	Standard deviation (denom. = n-1)
Faecal coliforms (n⁄100ml)	106	0	1500	85	13	280	242

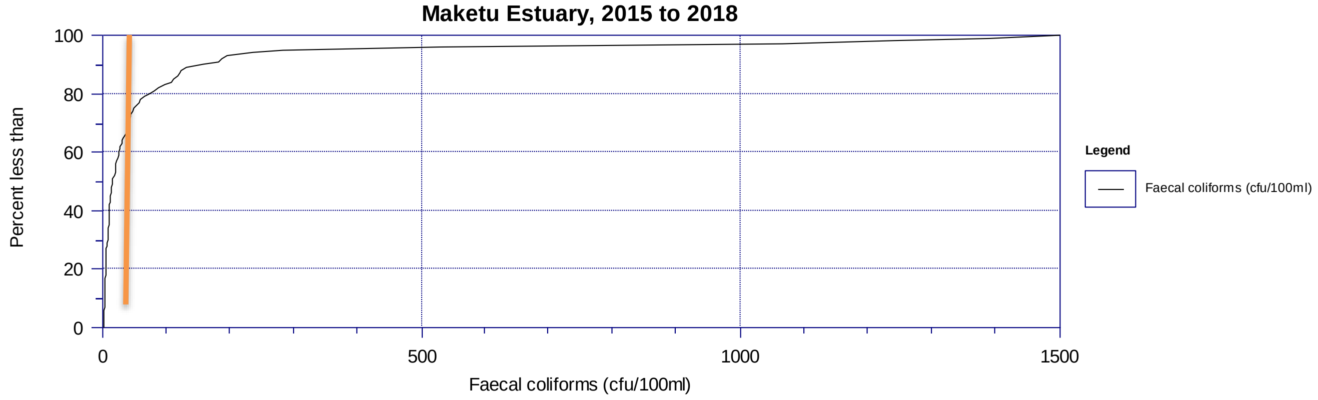


Figure 3.9: Frequency distribution of faecal coliform results from Maketū Estuary, 2015 to 2018 (43 FC/100ml concentration is shown in orange)

The Kaituna River re-diversion project is currently underway to increase the volume of water (particularly freshwater) flowing from the Kaituna River into Maketū Estuary so as to maximise the ecological and cultural health. The project will increase the total volume of water entering the estuary via Ford's Cut during a mean tidal cycle from about 153,700 m^3 to 574,500 m^3. There will be an overall increase in freshwater entering the estuary (133,700 m^3 to 436,600 m^3), but a decrease in the fraction of freshwater to saltwater (see Appendix Table 6.2). When converted to an average 24-hour equivalent flow, the volume of water entering the Maketū Estuary via Ford's Cut will increase from 3.43 m^3/s to 12.82 m^3/s and the volume of freshwater from the Kaituna River will increase from 2.98 m^3/s to 9.74 m^3/s (during a mean tide cycle and a mean river flow) (Hamill 2018). The faecal contamination load coming from the river will increase due to the larger freshwater input.

Modelling of set inflow FIB concentrations to Maketū Estuary from the Kaituna River by DHI showed similar results to this study with respect to the shellfish water guidelines - the median 14 FC/100ml being exceeded around 46% of the time. However, with increased flow to the estuary from the Kaituna diversion the median criteria of 14 FC/100ml is predicted to be exceeded 92% of the time (Jensen et al. 2010).

Similarly, the DHI model predicted that under the current conditions the 43 FC/100ml threshold for shellfish water would be exceeded 27% of the time. This corresponds well with the 26% of the time estimated here for the 2015 to 2018 data. DHI predicted this threshold would be exceeded 65% of the time with the increase in freshwater from the re-diversion of the Kaituna River.

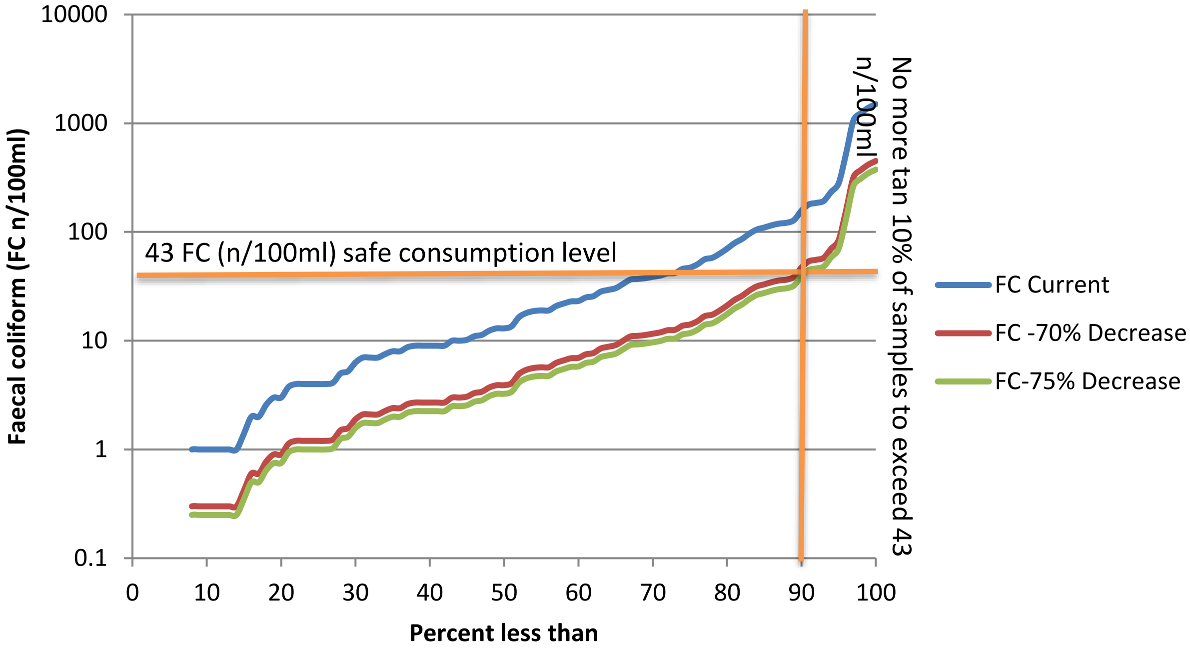


Figure 3.10: Projected changes in faecal coliform concentrations in Maketū Estuary needed to achieve “no more than 10% of samples exceeding 43/100 ml” compared to the current distribution (2015-18 data).

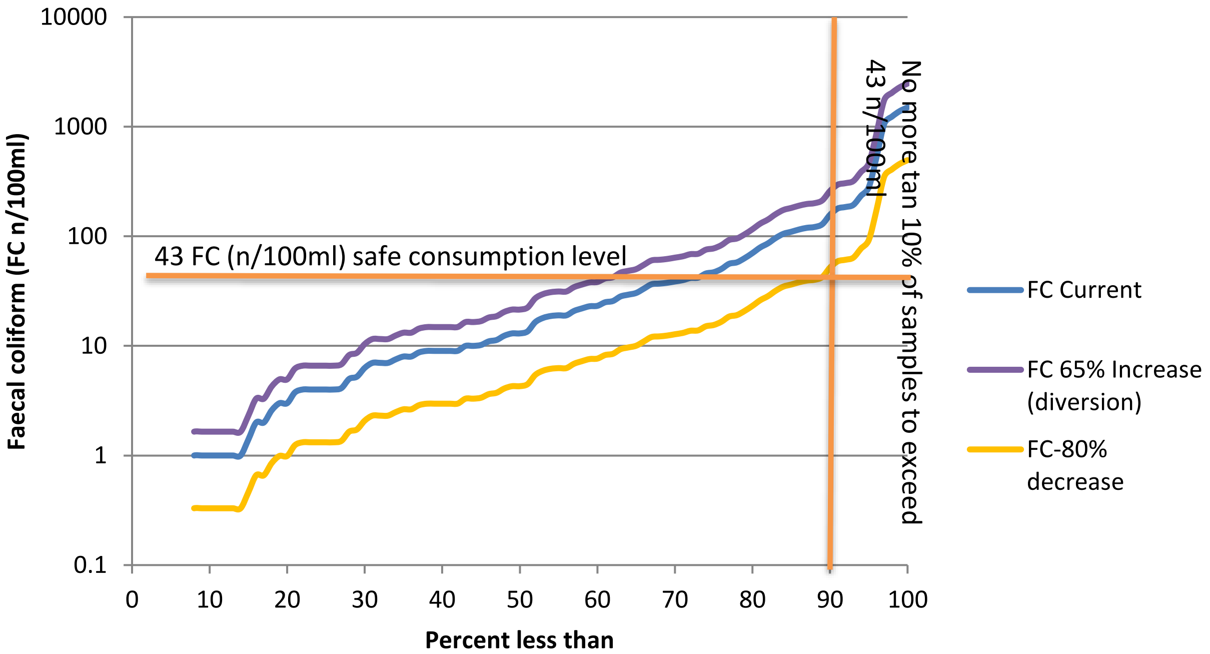


Figure 3.11: Projected changes in faecal coliform concentrations in Maketū Estuary needed to achieve “no more than 10% of samples exceeding 43/100 ml” following re-diversion. Note FC current is as for Figure 3.10 (2015-2018 data)

The level of reduction in faecal coliform bacteria required to reach the water quality objective of *no more than 10% of samples should exceed a MPN of 43/100 ml*, was modelled using the current level of faecal coliforms in the estuary. Movement of the faecal coliform distribution (2015-2018) indicates a greater than 70 percent reduction in faecal coliform concentration is required to achieve the shellfish water threshold (Figure 3.10). An approximate 80 percent reduction in concentration is required with the increased freshwater flow from the Kaituna River (Figure 3.11).

3.2.1 Faecal contamination in freshwater entering Maketu Estuary

Microbial contamination of Maketū Estuary occurs from multiple sources. The main load of faecal indicator bacteria to the estuary comes via the Kaituna River, Waitipuia Stream, and drains (Table 3.3). Hamill (2014) estimated that birds contribute 33% of the current median faecal coliform load entering via Ford's Cut, although the relative contribution from birds reduces to about 10% after the Kaituna River Re-diversion and Maketū Estuary Enhancement Project diverts more water to the estuary.

The concentration of *E.coli* bacteria are within bathing guidelines at Te Matai but increase downstream to exceed the guidelines at Te Tumu (i.e. a 95 percentile of 400 and 1890 cfu/100mL respectively). The higher bacteria concentrations at Te Tumu compared to Te Matai points to localised inputs from the Waiari, Ohineangaanga and Raparapahoe Streams, and drainage canals (Table 3.3). Hamill (2018) found no significant correlation between *E. coli* concentrations and flow in the Kaituna, although there are notable observations of increased *E. coli* concentrations with rainfall.

Table 3.3: Faecal Indicator Bacteria in the lower Kaituna River and drains to Maketū Estuary and lower Kaituna. Average of monthly median concentrations in the Kaituna River for the period 2010-2018, and drain data for the periods 2011-2013 and 2016-2017 (source Hamill 2018).

Site	E.coli (cfu/100ml)	Enterococci (cfu/100ml)	E.coli load (n/day)	E.coli load with diversion (n/day)
Kaituna at Te Matai	105	120		
Kaituna at Te Tumu	291	203	$7.49\text{x}10^{11}$	$2.45\text{x}10^{12}$
Waitipuia Stream	1424	1573	$3.14\text{x}10^{11}$	$3.14\text{x}10^{11}$
Singletons Pump Drain	1087	2110	$6.67\text{x}10^{10}$	$6.67\text{x}10^{10}$
Kaituna Road Drain	836	999	$6.65\text{x}10^{9}$	$6.65\text{x}10^{9}$
Ford Rd Drain u/s Pump station	1953	1914		
Diagonal Drain at Control Gates	907	876		
Totals			$1.14\text{x}10^{12}$	$2.84\text{x}10^{12}$

This analysis has not attempted to model the catchment contribution relative to estuarine FIB concentrations, as dilution is complicated by the diversion structure and the imminent change in freshwater input through the diversion structure. There will be times in the tidal cycle when a pulse of mostly seawater will come through Ford's cut, in addition to what is entering through the estuary mouth, changing the mix of fresh to oceanic water.

Overall, the increase in the freshwater from the Kaituna River drives a general increase in the concentration of indicator bacteria in the estuary derived from external sources (Hamill 2014). Given this prognosis, the initial aim for faecal contaminant reduction could be to strive for the bacterial load under current conditions. To achieve this, the catchment load to the estuary would need to be reduced by around 60 percent (this is difference between the predicted bacteria load after an increase of freshwater from the Kaituna compared to the current load).

The estimated catchment bacterial load reductions required may be lower if load results have been biased by a wetter period (i.e. increased flushing of bacteria to the estuary). Increased flushing from an increase in freshwater through the estuary could also reduce the re-suspension of bacteria from the sediments. However as stated for Waihī Estuary, mitigation actions in the catchment to reduce bacterial loading are likely to occur stepwise over time and the impacts of these can be measured and assessed against the relevant guidelines.

4 Summary Discussion

4.1 Catchment faecal load reductions and estuarine targets

In recent years bacterial water quality has failed (Waihī Estuary) or nearly failed (Maketū Estuary) to meet guidelines for shellfish consumption. While median faecal coliform concentrations have been less than 14 MPN/100mL, the 90 percentile of 43 FC/100ml guideline has been exceeded (in 36% and 26% of samples from Waihī and Maketū estuaries respectively). The amount of time the guideline has been exceeded varies over summer seasons, so estimates have been made on what reductions in the estuary are required based on available data. Estimates of the bacterial loading reductions required from the catchment and a corresponding load target are provided in Table 4.1.

Table 4.1: Estimated estuary faecal coliform reductions and catchment load targets to meet the shellfish water guideline value (90% of samples<43 FC/100ml).

	Waihi		**Maketū**		
			pre	**Post**	
	% Reduction	Target Load (n/day)	% Reduction	% Reduction	Target Load (n/day)
Estuary faecal coliform concentration reduction required	~80%		~70%		~80%
Catchment faecal coliform reduction required and corresponding load target	~50%	9×10^{11}		~60%	1.1×10^{12}

The bacterial load reductions required from the catchments of both estuaries are not dissimilar, with potentially a larger reduction required for the Maketū catchment once the freshwater diversion increase has occurred. Although the Kaituna River input does have a significant impact on water quality in the estuary, the original re-diversion in 1996 resulted in improved microbial water quality rather than a decline. Flushing effects may limit predicted increases in bacterial concentrations in the Maketū Estuary.

4.2 Limitations and assumptions

Faecal indicator bacteria concentration data from inflow sampling sites was used to estimate mean annual loads. These data are subject to error in sampling and analysis. Given the variability of FIB concentrations over time, determination of average catchment concentrations and yields is known to be difficult (Muirhead, 2015, Wilcock, 2006). The measured loads were determined using concurrent flow data where flow data were available. However, there was only limited data for the Pokopoko-Mangatoetoe Stream (Kaikokopu canal) compared to the other three inflows which introduces some bias to the overall predicted load of *E.coli* to the estuary.

One assumption is that the reduction in faecal contaminant loading from the catchment (as measured by FIBs) will result in an equivalent reduction in the estuary. However, this may not necessarily be the case as deposition, resuspension and other faecal contamination sources (e.g. avian) may add to the loading in the estuary. If a reduction of loading from the catchment resulted in an exponential decrease in the estuary (rather than a linear decrease as has been assumed in this report) then greater gains may be made by some mitigation measures. It is likely that reductions from mitigation actions in the catchment will be undertaken in a stepwise fashion and the benefits of this will be able to be assessed by further monitoring and modelling.

Modelling has also been undertaken based on a past (known) set of conditions. These conditions may change (e.g. there may be more intensive rainfall events due to the effects of climate change) and therefore the reduction targets may also need to change.

No decay component for FIB was used in the analysis as data used from the SOURCE model has a decay component, and once bacteria are in the estuary some decay is implicit in the dilution estimates.

The re-diversion project will reduce the load of microbes from sediment re-suspension (by increased flushing), but it will also increase the external load of microbial contamination from the Kaituna River. It is uncertain as to whether internal loading or external loading is more important in driving microbial contamination of shellfish in Maketū Estuary, so it is unclear whether the re-diversion will improve or worsen the microbial contamination of shellfish in the estuary (Hamill 2018). There are also other sources such as wildfowl, septic tanks and direct stormwater runoff that were not included in the load estimates, but these can have a significant impact in localised parts of the estuary. For example avian sources have been estimated by Hamill (2014) to be a significant addition to Maketū Estuary (around 30% of the current load).

There is a moderate to high level of confidence in the concentration reductions required to meet shellfish water thresholds consistently in the estuaries. Longer term and recent data have very similar distributions giving some confidence that the data repesents the faecal coliform concentrations in the estuaries (e.g. Figure 3.1). Faecal coliform data for both estuaries have a similar variance and standard error (see Appendix, Figure A3). As the standard error around the mean for faecal coliform concentration is relatively small this gives some confidence in the precision of the reduction estimates.

Less certainty exists around the faecal contaminant loads to the estuaries for the reasons explained above. The level of confidence around the catchment load targets required to achieve shellfish water guidelines in the estuaries is at the scale of 0.5-1 log(10) order of magnitude. Hence, there is a moderate level of uncertainty around these daily load targets. The relative percentage reduction of load required may be 10 to 20% lower (or higher) than estimated.

Given the level of uncertainty in faecal contaminant loads from the catchments, there will be a requirement to track progress towards environmental objectives and to measure the effectiveness of policies and interventions. Monitoring and modelling recommendations have been made by Jensen et al (2012) for the Maketū Estuary, and similar recommendations and modelling would be useful for Waihī Estuary also. Monitoring and modelling that can assess and quantify the change in state over time and space will need consideration, possibly including more intensive monitoring of the estuarine receiving environment to support dynamic estuarine models.

SOURCE modelling will also be useful in evaluating the potential impact of catchment interventions designed to realise estuary objectives.

5 References

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6 Appendix 1

6.1 Faecal indicator bacteria relationships – Waihī Estuary

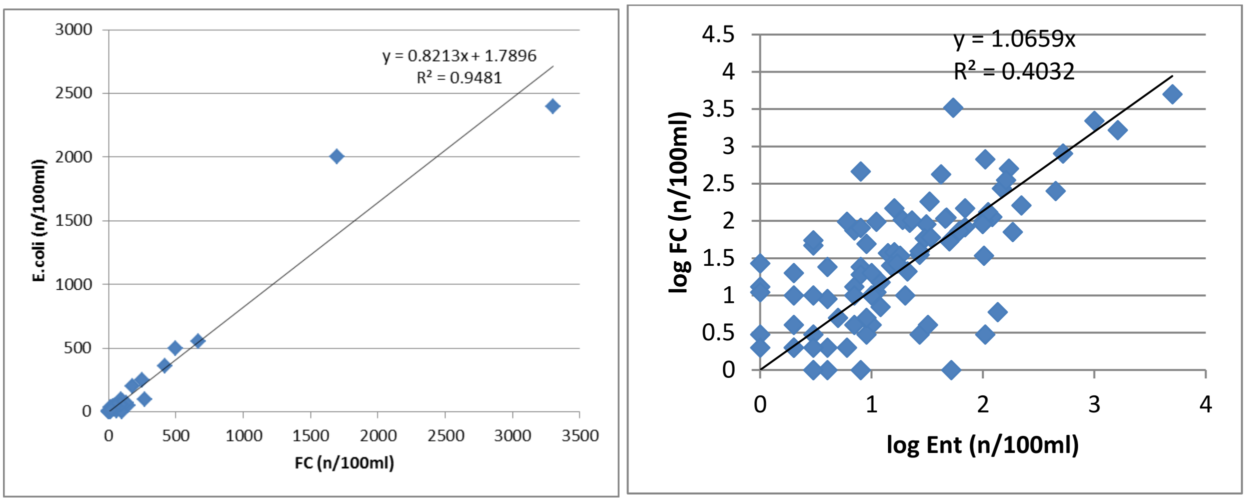


Figure A1: FIB relationships for Waihī Estuary data, 2012 to 2018.

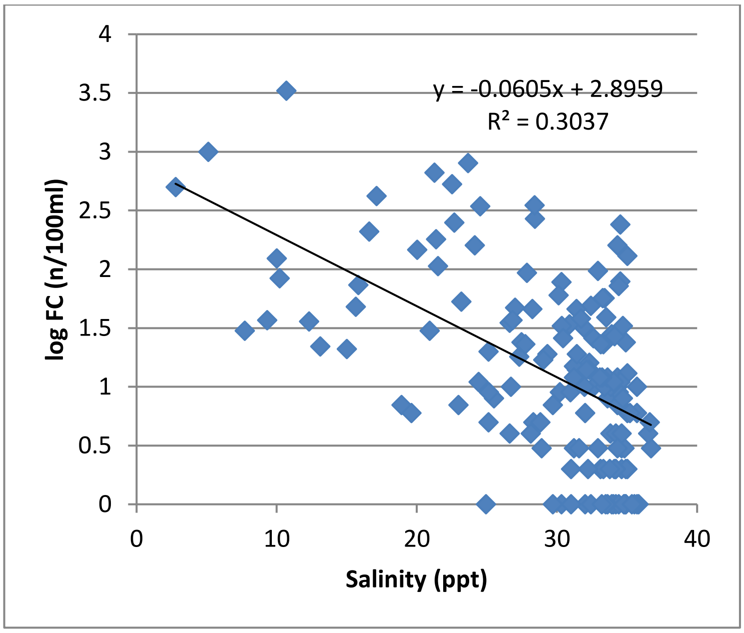


Figure A2: Salinity vs log faecal coliform concentrations, Waihī Estuary.

6.2 Estuary characteristic volumes and areas

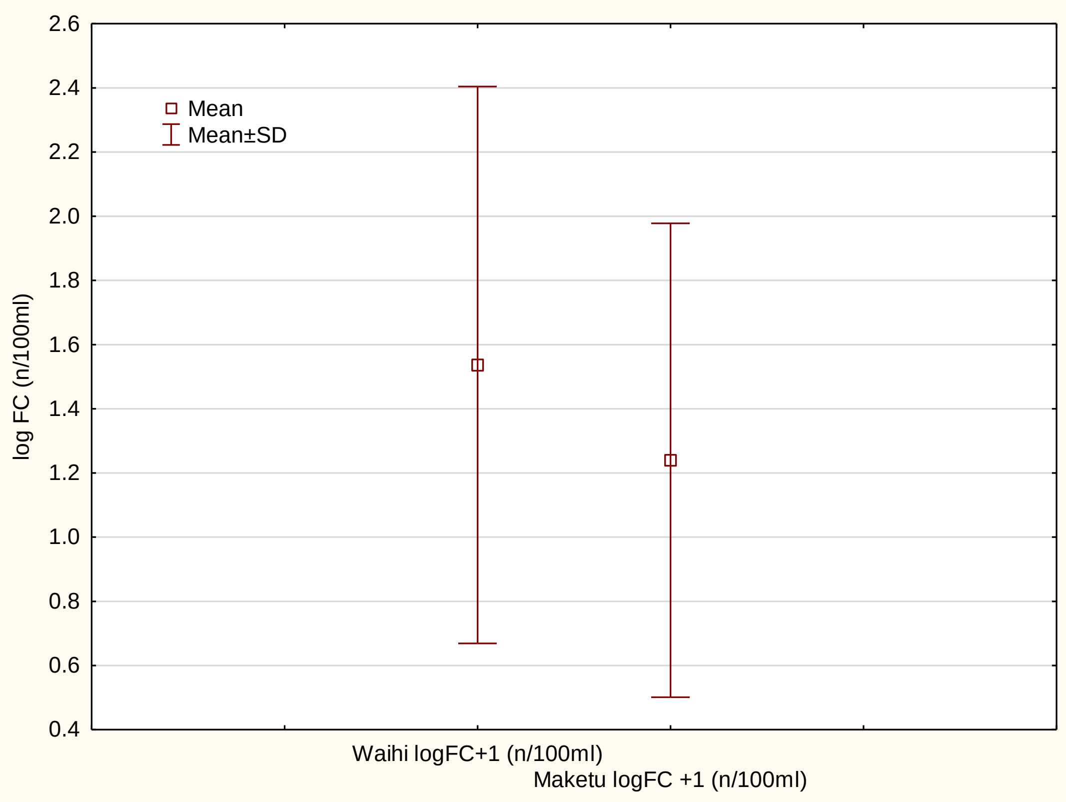
Table 6.2: Estuary characteristics.

	Maketū (pre-diversion)	Maketū (post-diversion)	Waihī
Total estuary area (ha)	255.9		338.8
Channels (ha)	54.3		41
Sand/mudflats (ha)	192		221
Saltmarsh (ha)	9.6		76.8
Subtidal Estuary volume (m^3)	217,200		246,000
Tidal prism P (m^3)	959,300		2,358,000
Estuary volume V (m^3)	1,176,500		2,604,000
Freshwater Inflow/day (m^3)	291,168	872,640	911,520
Freshwater inflow (m^3/s)	3.37	10.1	10.6
Ratio of Freshwater/saltwater (at mean river flow)	0.87	0.76	
Flushing potential	0.75		0.35
Dilution potential	0.000000024		1.09E-08
Approximate mean tide area (ha)	245		290

6.3 Faecal indicator bacteria Statistics –Estuarine

Table 6.2: Faecal indicator statistics for Waihī Estuary 1989 to 2018.

Variable	Sample size	Minimum	Maximum	Mean	Median	Standard deviation (denom. = n-1)
E coli (cfu/100ml)	164	0	2400	78.7	4.5	314
Enterococci (cfu/100ml)	224	0	5000	81.8	7	424
Faecal coliforms (cfu/100ml)	224	0	5000	112.4	10	461



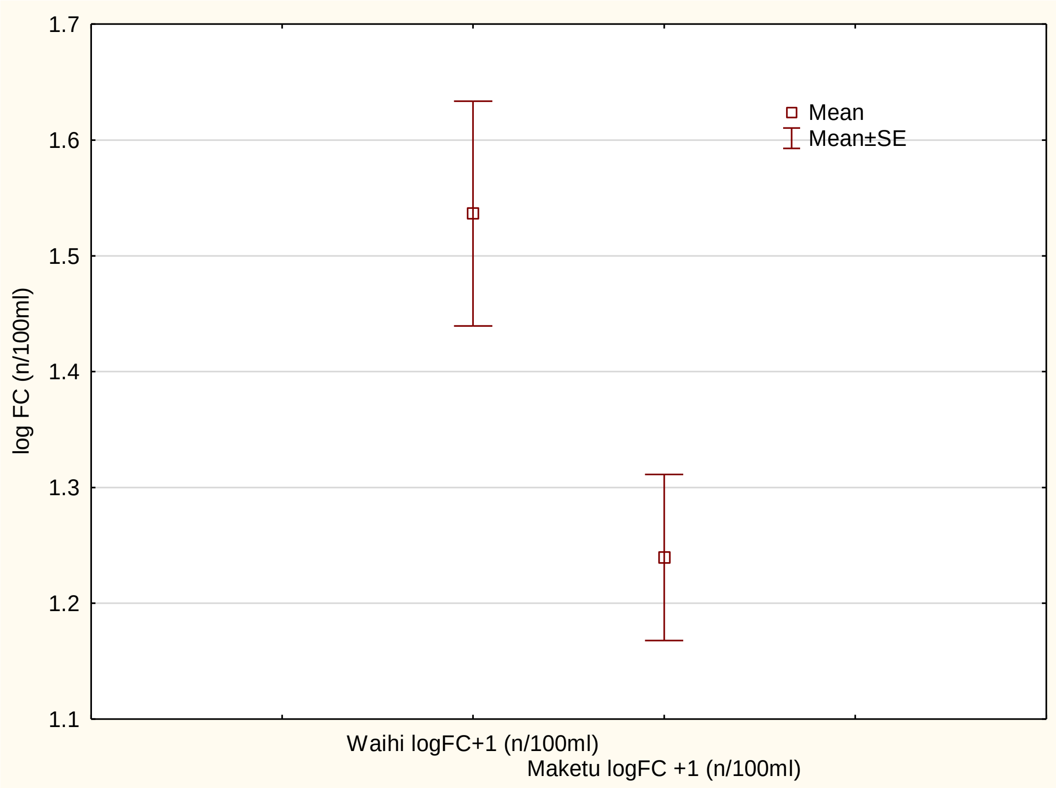


Figure A3: Mean and standard deviation (SD=1) (top), and mean and standard error (bottom) of faecal coliform results from Waihi and Maketū estuaries, 2015 to 2018 data.