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Potential sources of faecal contaminants in four Coromandel catchments

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Executive summary

In 2015, Waikato Regional Council (WRC) carried out a water quality snapshot survey in 18 coastal stream mouths in Coromandel, New Zealand (WRC, 2016). Based on the results of the 2015 survey, four catchments were selected for further investigation between January and March 2017: Stewart Stream, Opito Bay; Kuaotunu Stream, Kuaotunu; Taputapuatea Stream, Whitianga; and Pepe Stream, Tairua.

The aim of this further investigation was to gain a more comprehensive understanding of 1) where contaminants were derived within the catchment, 2) whether the source of contamination is animal or human-derived, and 3) how these levels of contaminants are affected by different weather and tide events, with the aim of informing future targeted management intervention.

We identified the source of faecal contamination (*E. coli*) down to a sub-catchment level or by land use by sampling downstream of confluences or by sampling downstream of a specific land use type. Each of the catchments had similar land use composition; typically, native bush or pine forests in the upper catchment, agriculture in the mid-catchment, and small urban development nearest the coast. We carried out event-based sampling to investigate faecal contamination levels during dry and wet weather and during spring and neap tides at the stream mouths.

The results indicate that in general:

1. *E. coli* concentrations were highest after heavy rainfall.
2. *E. coli* concentrations were highest at the pastoral and stream mouth sites and lowest at the native/exotic bush sites.
3. At the stream mouth, *E. coli* concentrations were more likely to be elevated during a spring tide than during a neap tide.

Faecal source tracking analysis identified a variety of faecal contaminant sources. Possum and avian sources were present in dry and wet weather conditions and ruminant sources dominated in wet weather conditions.

There was a strong agreement between the land use type and the source of faecal contamination detected. Possum and avian sources were commonly detected at the bush sites and ruminant sources dominated downstream from pastoral sites. Typically, we detected a mixture of all three main contaminant sources, possum, avian, and ruminant, at the stream mouth.

The combined approach of sampling downstream of confluences and land use types, event-based sampling, and faecal source tracking has proven to be a useful tool for identifying the source of faecal contaminants that are detected at times in estuaries, including coastal stream mouths. The findings from this approach can assist in determining whether catchment-based management actions would be beneficial for improving water quality, and if so, where efforts are best spent.

1 Introduction

The Coromandel Peninsula has many beaches that are popular amongst locals and the many tourists that visit each year. Most beaches have small streams flowing into them with water that is typically warm and slow flowing. At times, storms and coastal processes can result in stream mouths becoming partially or completely blocked off from the open coast forming small lagoons which are often used as popular swimming and wading locations for younger swimmers and families.

In 2015, Waikato Regional Council (WRC) carried out a snapshot of water quality in 18 coastal stream mouths in the Coromandel to investigate two aspects regarding water quality: 1) the ecological health of the system, and 2) the concentration of faecal bacteria that, at high levels, can indicate a potential human health risk. This snapshot showed that the water quality in these stream mouths was highly variable and particularly susceptible to contamination from excess sediment, nutrients, and faecal bacteria during and following rainfall and during spring tides (Wilson 2016).

The purpose of the 2015 snapshot was to identify the state of the water quality at stream mouths over the summer months. In particular, the snapshot focussed on faecal contaminants, how frequently the concentration of contaminants exceeded recommended guideline values, and identifying potential sources of the contaminants (e.g., humans, ruminant animals, gulls, possums, and pigs).

This study further builds on the 2015 snapshot by carrying out more comprehensive catchment assessments to determine: 1) where contaminants were derived within the catchment, 2) whether the source of contamination was animal or human, and 3) how these levels of contaminants were affected by different weather and tide events. Results from this type of approach will assist in determining whether catchment-based management actions would be beneficial for improving water quality, and if so, where efforts are best spent.

We selected four catchments of interest based on the number of exceedances of the recreational water quality guidelines at each site in the previous 2015 snapshot survey and the general swimming popularity of the (Figure 1):

1. Stewart Stream, Opito Bay;
2. Kuaotunu Stream, Kuaotunu;
3. Taputapuatea Stream, Whitianga; and
4. Pepe Stream, Tairua.

In each catchment, we selected sampling sites downstream of confluences and land use types in order to isolate the source of faecal contamination to sub-catchments and land use. Each of the catchments had similar land use composition; typically, native bush or pine forests in the upper catchment, agriculture in the mid-catchment, and small urban development nearest the coast. In this report, we refer to these three land use types as bush, pastoral, and stream mouth sites.

We analysed water samples for a range of physical parameters, nutrients, and faecal contaminants. Where appropriate, we also carried out faecal source tracking (FST) to identify the specific source of faecal contamination; in this study, human, ruminant (more specifically cow or sheep where possible), bird, and possum.

Figure 1: **Locations of the Pepe Stream, Taputapuatea Stream, Kuaotunu Stream, and Stewart Stream catchments investigated in this report.**

We carried out event-based sampling to investigate various weather and tide events:
1. wet weather;
2. dry weather;
3. spring tides; and
4. neap tides.

In addition to furthering Council's understanding of water quality in the sampling locations, this investigation provides a showcase of how the latest scientific techniques and tools can be used to identify the location and cause of degraded water quality in Waikato's coastal environment. These types of investigations help to build a better understanding of catchment-specific sources of estuarine contamination which can ultimately inform robust, science-driven management responses.

2 Methods

2.1 Catchment selection

We selected catchments of interest based on the number of exceedances of the recreational water quality guideline at each site in the previous 2015 snapshot survey and the general swimming popularity of the location.

In each of the catchments, we sampled at three separate locations to gain an understanding of contaminant sources throughout the catchment specific to the various land use types. We placed a sampling location downstream of a confluence to isolate sub-catchments or downstream from specific land uses to isolate a land use. Generally, we placed one sampling site in the upper catchment downstream from the native/exotic forest, another site downstream from pastoral land use in the middle of the catchment, and one site at the stream mouth to capture the urban land use in each catchment (Figure 2; more details in Appendix 4).

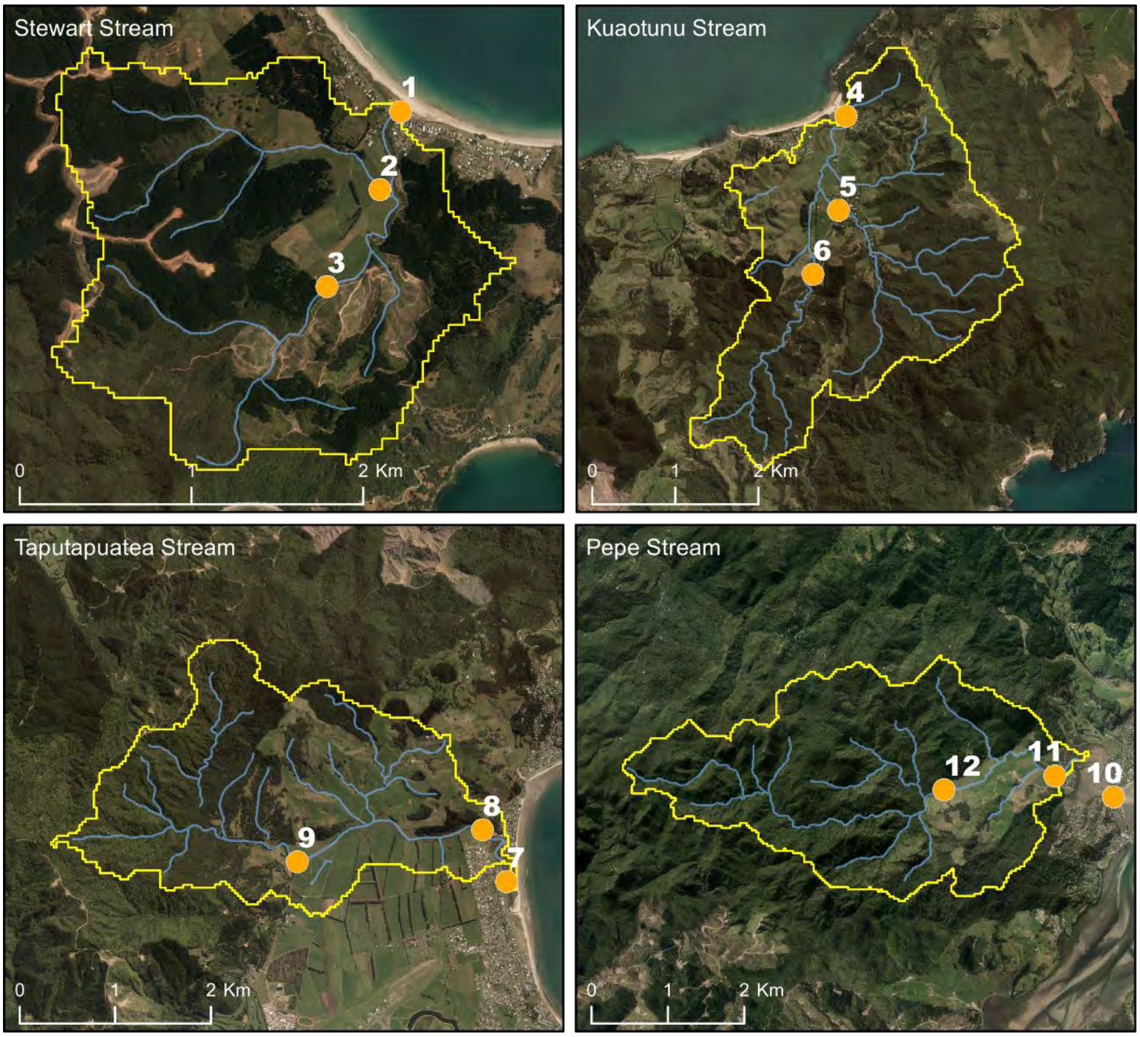


Figure 2: **Sampling locations within each catchment.**

2.2 Stream velocity

We measured stream velocity to get a better understanding of the total loading of contaminants that are washed down the stream into the coastal marine area. To calculate this, we timed how long it took an object to float 5 m downstream. We used the average time of the three replicates to account for variations in velocity; for example, stream banks are associated with greater friction, and hence slower moving water.

In order to calculate the discharge rate from the stream velocity, we also measured the stream's cross-section at each sampling site. We measured the depth of the stream at approximately 0.5 m intervals along a transect that was perpendicular to the stream flow direction.

We calculated the stream discharge rate, or the volume of water flowing in a stream over a set interval of time, using the following equation:

$$Q = AV$$

Where Q is discharge (m^3/second, also called cumecs), A is the cross-sectional area of the stream (m^2), and V is the average velocity (m/s).

By calculating the area of each subsection (width of sub-section x depth of subsection) and multiplying it by the stream velocity, we could calculate individual discharge rates for each sub-section of the stream. We then calculated the sum of the individual spot discharge rates to approximate the total stream discharge rate.

2.3 Rainfall

Rainfall is a key climatic factor that influences the concentration of faecal bacteria in waterways. Rainfall flushes contaminants off the land and into surrounding waterways. Heavy rainfall can also lead to stormwater inflow and infiltration of reticulated or on-site wastewater systems that can result in overloading, poor treatment and in some cases overflows.

In this investigation, we used daily rainfall values taken from the Waikato Regional Council rain gauge at Castle Rock in the Matawai Catchment recorded from 21 December 2016 through to 1 April 2017 to provide extra information about potential causes of contamination in the waterways.

2.4 Weather and tide events

We scheduled our sampling based on weather and tide events. More specifically, we carried out two rounds of sampling for each of dry weather, wet weather, spring tide, and neap tide events, with 64 samples being collected in total (48 samples collected for two rounds of dry sampling and wet sampling and 16 samples for two rounds of spring tide sampling and neap tide sampling).

One team collected samples over two days for every round of sampling for the ‘dry period sampling’, ‘spring tide sampling’ and ‘neap tide sampling’. Two separate teams sampled all four catchments in a single day for each round of ‘wet weather event sampling’. This allowed us to collect all samples within a specific time window to enable a greater level of comparability between sites.

We defined the trigger for a ‘wet weather event’ category, for the purpose of this investigation, as a minimum of 10 mL of rainfall during a one hour period. We carried out sampling within 10 hours of this trigger being reached.

2.5 Discrete water sampling

We collected discrete water samples following the 4Sight Water Quality Sampling Guidelines for Incident Management (4Sight 2017).

We collected samples from the upper catchment site first followed by the mid-catchment site and lastly at the stream mouth. For spring and neap tide events, we collected samples approximately one hour after high tide when sampling at each stream mouth.

We used sterile 400 mL bottles to collect water samples for microbiological analyses (*E. coli*, enterococci, and faecal source tracking) and a 1 L plastic bottle to collect water for all other parameters.

We placed water samples on ice immediately after collection and delivered them to Hill Laboratories in Hamilton within 24 hours of collection. We measured water salinity onsite using a handheld instrument (YSI ProDSS) at the stream mouth sampling locations to direct the laboratory to the appropriate water analyses (methods differ for fresh and marine samples).

2.5.1 Water quality measurements

Field staff used hand-held instruments (YSI ProDSS) to measure water temperature, dissolved oxygen, pH and conductivity/salinity at all sites. Salinity readings provide information about the proportion of freshwater and oceanic water at the stream mouth sites and, at times, mid-catchment sites that are tidally influenced.

The laboratory analysed each water sample for a range of parameters, including suspended sediment, nutrients, and faecal bacteria. Method details and detection limits are available in Appendix 2.

2.6 Faecal source tracking

The high cost of faecal source tracking restricted us from analysing all samples collected in this investigation. Instead, the laboratory filtered all water samples (0.54 µm), added a buffering agent to preserve the integrity of the sample, and froze them. This allowed us to carry out faecal source tracking at the end of the sampling period and only on samples that exceeded the recreational water quality guidelines (>550 *E. coli* per 100 mL or >280 enterococci per 100 mL).

Selected samples were analysed for the following DNA markers to identify the source of faecal contamination:

- human;
- avian (ducks, swans, seagulls, geese, and chickens);
- ruminant (cows, sheep, goats, and deer); and
- possum.

The laboratory also tested more specifically for cow and sheep markers in samples with high ruminant marker concentrations.

2.6.1 Interpreting FST results

In some situations, the markers used for faecal source tracking cross-react with other contaminant sources causing a false-positive result. This is the case for the primary human marker which can cross-react with faecal material primarily from possums but also some other animals. To mitigate this, the laboratory analysed two separate human markers and would only confirm the presence of human sources if both markers were detected.

This is particularly an issue in catchments with large areas of native bush, such as the catchments monitored in this investigation. Results, therefore, need to be interpreted with caution so as not to assume a human source of contamination when the source could potentially be of possum origin. This is further discussed in the Results and Discussion section of this report.

2.7 Guideline values

We use a variety of water quality parameters as indicators of 'ecological health' or suitability for contact recreation (Table 1).

The 2003 Ministry of Health and Ministry for the Environment recreational water quality guidelines[1] recommend measuring faecal bacteria to indicate the suitability of the water for human contact recreation (e.g., swimming, surfing, or wading; Table 2). In freshwater, we measure the levels of *E. coli* and in marine waters we measure enterococci.

Measuring different indicator bacteria in fresh and marine waters makes it difficult to fairly compare results between upper catchment sites (fresh) and stream mouth sites (marine). The recreational water quality guidelines recommend against measuring enterococci in freshwater as these bacteria are more likely to originate from natural sources such as decaying leaf matter than *E. coli*. For this reason, and to enable a fair comparison between all sites along the stream, we used *E. coli* concentrations to indicate the suitability for contact recreation at all sites, including the stream mouth. We checked for any discrepancies using this approach by looking

[1] http://www.mfe.govt.nz/fresh-water/tools-and-guidelines/microbiological-guidelines-recreational-water

at whether marine samples that exceeded the recreational water quality guideline for *E. coli* similarly exceeded the recreational water quality guideline for enterococci.

Table 1: Water quality parameters, their relevance, and the guideline value used to assess the current environmental state for freshwater. Where applicable, guideline values for ecological health and contact recreation parameters were obtained from WRC guidelines[2]. Where WRC had no guideline, ANZECC guidelines[3] were used for ecological health parameters and the recreational water quality guidelines[4] for contract recreation parameters.

Water quality variable	Relevance	Guideline value	Unit
Ecological health			
Dissolved oxygen saturation	Oxygen for aquatic animals to breathe	Upper limit: 110 Lower limit: 80	%
Turbidity	Can restrict plant growth	10	NTU
Total nitrogen	Can cause nuisance plant growth	0.5	g/m^3
Nitrate-N + nitrite-N	Can cause nuisance plant growth	0.04	g/m^3
Total ammoniacal-N	Can be toxic to fish	0.88	g/m^3
Total phosphorous	Can cause nuisance plant growth	0.04	g/m^3
Dissolved reactive phosphorus (DRP)	Can cause nuisance plant growth	0.02	g/m^3
Contact recreation			
E. coli	Human health	550	cfu/100 mL

Table 2: Trigger levels for *E. coli* in freshwater from the recreational water quality guidelines[3].

Highly likely to be uncontaminated (green) (<260 *E. coli*/100 mL)
Potentially contaminated (amber) (260–550 *E. coli*/100 mL)
Highly likely to be contaminated (red) (>550 *E. coli*/100 mL)

3 Results and Discussion

3.1 Trends observed across all catchments

In this section, we present the key findings from this investigation. More detailed descriptions of the results are presented in Appendix 1 and analytical results in Appendix 3.

3.1.1 *E. coli* concentrations were highest after rainfall

The main observation from this investigation was that *E. coli* concentrations were highest during rainfall events (Figure 3). It's common to see elevated levels of faecal contaminants during and after rainfall in all types of water as contaminants are flushed off the land and into nearby waterways.
We can, therefore, conclude that the highest risk to recreational water users would be after heavy rain at all sites.

[2] https://www.waikatoregion.govt.nz/environment/natural-resources/water/rivers/healthyrivers/how-we-measure-quality/
[3] http://www.mfe.govt.nz/publications/fresh-water/anzecc-2000-guidelines
[4] http://www.mfe.govt.nz/fresh-water/tools-and-guidelines/microbiological-guidelines-recreational-water

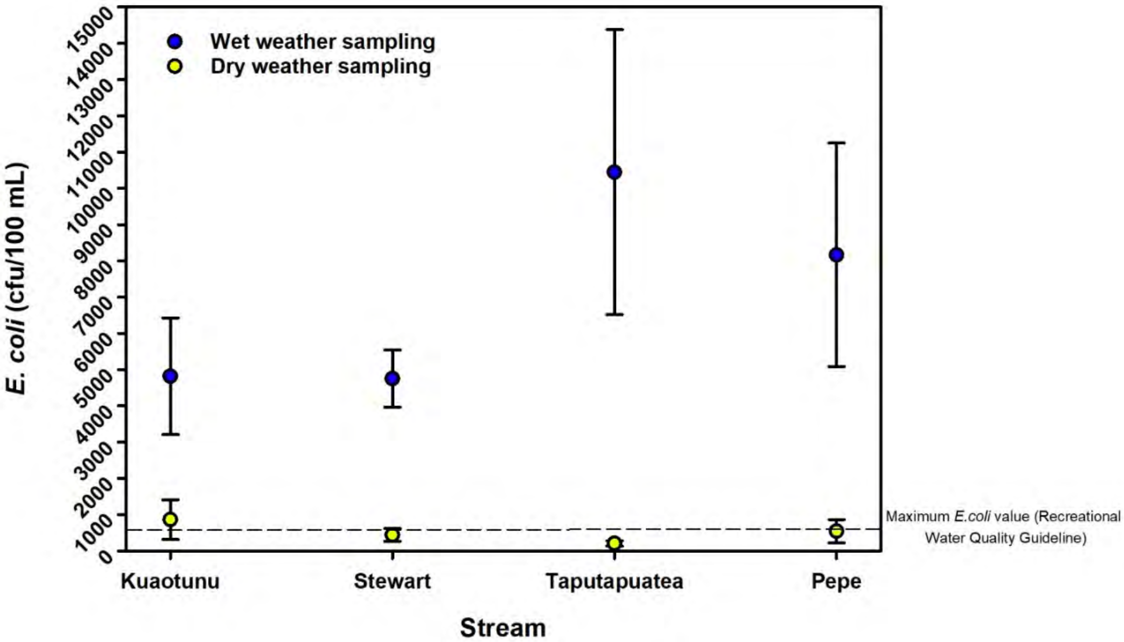


Figure 3: Average catchment *E. coli* concentrations during dry and wet weather conditions.

Of the two wet weather events we sampled, *E. coli* concentrations were highest at most sites on the second wet weather event at all sites and catchments. The likely cause of this was the greater amount of rainfall in the preceding 24 hours before sampling on the second occasion than on the first (27 mm of rain in 24 hours preceding to sampling event one cf. 61 mm of rain in 24 hours preceding sampling event two).

A second contributing factor may have been the large amounts of rainfall that were received in the Coromandel throughout the month of March between the two sampling events (10 February – 25 March). High rainfall during this time may have saturated soils throughout the Coromandel, reducing the ability of the soil to absorb further rainfall. This, in turn, may have increased the amount of runoff from the land and ultimately increased the amount of faecal contaminants washed into the waterways.

3.1.2 *E. coli* concentrations were influenced by land use

Each of the catchments had similar land use in that the upper catchment was in native bush or forest, the mid catchment was pastoral land and nearest the coast was small urban development. Each of these land uses has typical sources of faecal contamination. For example, the most likely sources of faecal contamination in native or exotic bush are possums and birds; for pastoral land, the most likely sources of faecal contaminants are ruminant animals. Sources of faecal contamination near urban areas are most likely to be from birds that inhabit reserves, coastal vegetation and intertidal areas, and potentially human sources from faulty wastewater systems and infrastructure. Point source discharges relating to individual consents for discharges of contaminants can also be potential contamination sources. Maps identifying current consents in each catchment are presented in Appendix 4.

When considering concentrations of *E. coli* in each catchment in relation to the surrounding land uses, results indicated that *E. coli* levels were highest in the pastoral land areas, particularly during dry weather events (see Figure 4). This indicates that pastoral land use is potentially contributing the largest portion of *E. coli* to the streams. This is reflected in the contaminant loads (presented in Appendix 6) calculated for all sites, which were generally larger in the pastoral sites than at the bush and urban sites. Statistical analyses showed that *E. coli* concentrations were statistically significantly higher at pastoral sites than at bush and urban sites during dry weather. There was no statistical difference between *E. coli* concentrations at any land use during wet weather, however, the mean *E. coli* concentration at pastoral and stream mouth sites was substantially greater (~8000 cfu/100 mL) than at bush sites (~5000 cfu/100 mL).

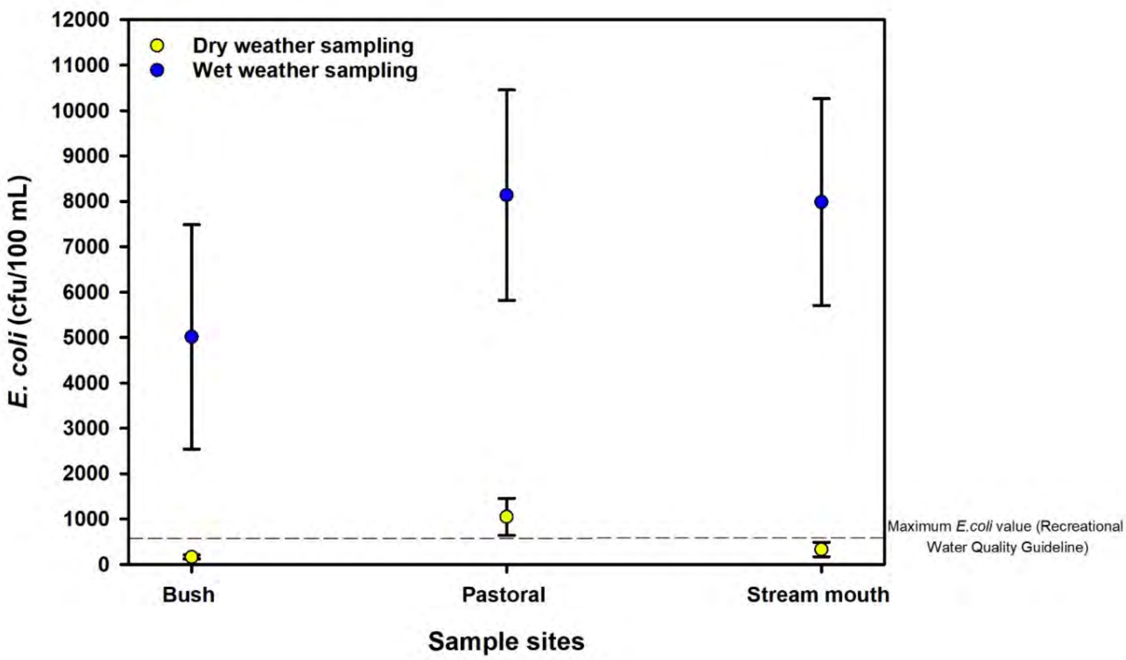


Figure 4: **Average *E. coli* concentrations for all catchments at bush, pastoral, and stream mouth sites during wet and dry weather events.**

E. coli levels at the bush sites were always lower than at the other sites. We also found *E. coli* levels to be elevated at the stream mouth (urban) locations above those found in the bush sites. This indicates that contamination accumulation is taking place down the length of the stream, followed by tidal flushing and dilution of contaminants at the stream mouth sites. However, despite the potential for the dilution of contaminants at the stream mouth sites, these sites can still pose the highest risk to human health overall. This is because the overall risk of a site is a combination of the concentration of a contaminant in the water, combined with the likelihood of human exposure to that water. Since the stream mouth sites are most used by people for recreational activities, they tend to present the highest human health risk overall, even if the concentrations of contaminants are higher in the mid or upper catchment.

These sources of contaminants are based on the location within the catchment and are dependent on our pre-selected sampling locations. To better understand the potential human or animal sources of these contaminants, we also used FST, which is discussed in Section 3.2.

3.1.3 *E. coli* concentrations were often elevated during a spring tide at the stream mouth

On most sampling occasions at the stream mouth, *E. coli* concentrations were higher during a spring tide than they were during a neap tide (Figure 5). The greatest difference between the water levels at high and low tide is during a spring tide. It’s during this time that low-lying land surrounding the waterway is most likely to be flooded, washing contaminants into the water. Two potential sources of faecal contamination in these low-lying areas are 1) grass-covered reserves and 2) septic tanks and irrigation fields.

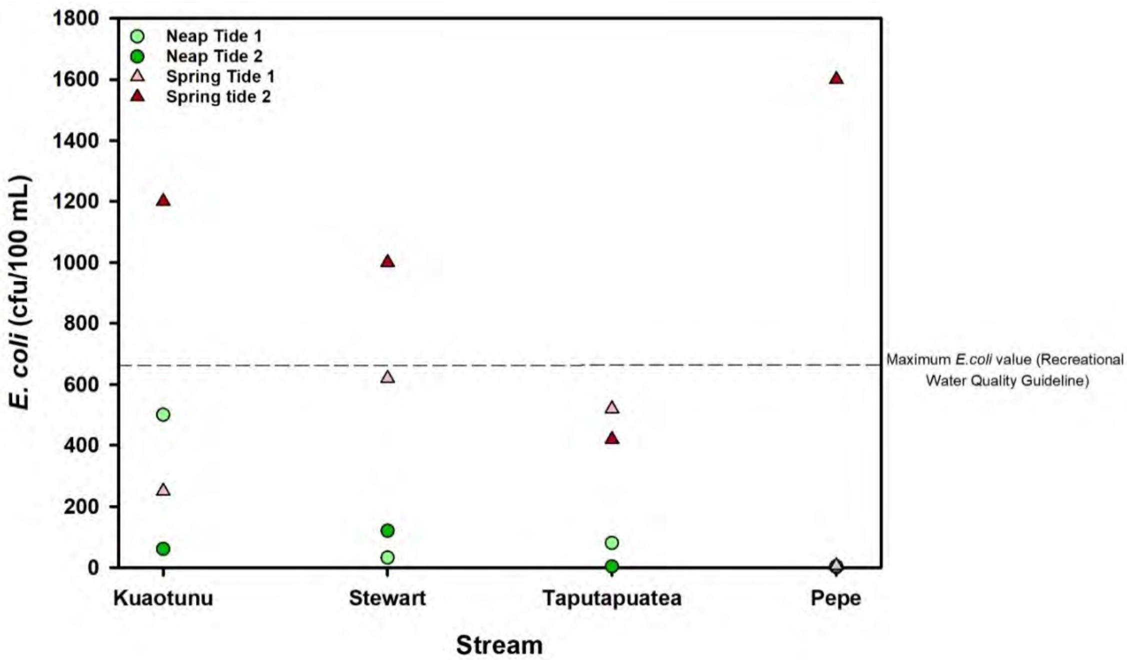


Figure 5: ***E. coli*** **concentrations at stream mouth sampling locations during spring and neap tides for each catchment.**

In each of the four catchments, there is a grass-covered reserve area near the stream mouth that is often populated by birds and is also a popular location for visitors and locals to walk their dogs. The contaminants from these animals may accumulate on the land during dry periods and then be washed into the nearby waterway after rainfall or flooding, temporarily increasing the levels of faecal contaminants. FST identified avian faecal markers at times, but they were not substantially higher during spring tides than they were on other occasions. In the previous 2015 snapshot, dog markers weren't identified by FST so were not run on this occasion.

Human markers were only identified on one occasion at each of Taputapuatea and Kuaotunu Streams and at levels that were below the FST limit of quantification; that is, FST identified the presence of both human markers but was not able to assign it a value because of its low concentration. This indicates that it is unlikely that septic tanks and irrigation fields were a major source of faecal contamination on these sampling occasions.

Such low levels of faecal contaminants from dogs (previously), birds, and humans indicates that, in this situation, the effect from these sources is lower than the FST approach was able to detect. This also implies that the primary source of faecal contamination at the stream mouth is from upstream.

3.1.4 Elevated *E. coli* concentrations were often accompanied by elevated nutrient concentrations

During wet weather sampling, when *E. coli* concentrations were elevated, nutrient concentrations were also elevated (Figure 6). The most likely reason for this is that the main source of faecal contamination is from runoff, which typically has elevated nutrient concentrations. Rainfall and flooding of low-lying land wash accumulated contaminants (e.g., faecal bacteria and nutrients) into the surrounding waterways. Common sources of these contaminants include the excess application of fertilizers or effluent to land.

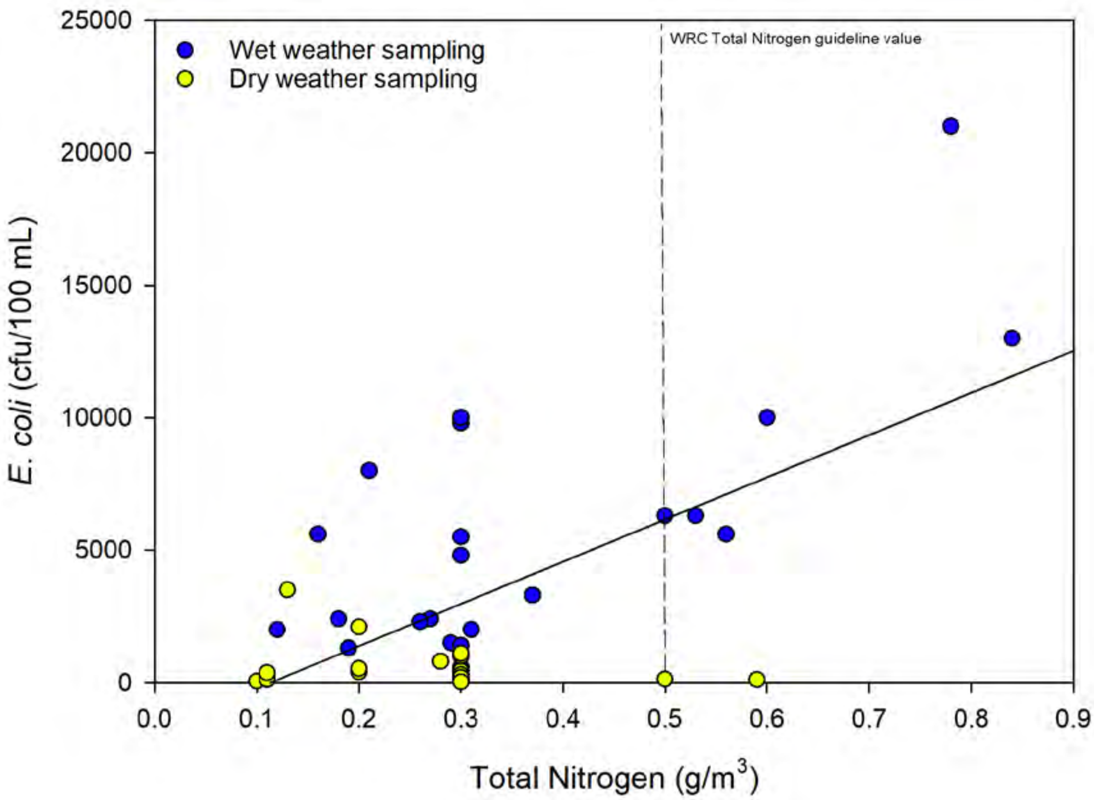


Figure 6: **Total nitrogen concentration vs *E. coli* concentration during wet and dry weather events. The line of best fit through the data is shown for wet weather sampling (R^2 = 0.4).**

3.2 Catchment summaries

3.2.1 Pepe Stream, Tairua

3.2.1.1 Bush site observations

Figure 7: Pepe Stream – Bush site (Site 12).

The bush site of Pepe Stream was fenced off and was well shaded by the bush canopy cover. The water at this site was visually significantly clearer than the other sites in the catchment with minimal suspended sediment observed on each monitoring occasion. This site also had the highest flow rate of all the sites in all four catchments that we monitored in this investigation.

E. coli concentrations were within the recreational water quality guidelines during dry weather sampling. We did, however, see elevated levels of *E. coli* after rainfall that exceeded the recreational water quality guidelines. Faecal source tracking showed that possums were one of the likely sources of *E. coli*.

3.2.1.2 Pastoral site observations

Figure 8: Pepe Stream – Pastoral site (Site 11).

The pastoral site in Pepe Stream was fenced off and had some riparian planting along the stream bank. This site was located in the middle of a dairy farm with cows always being nearby. This site was tidally influenced and slow flowing, sometimes with water flowing back upstream on an incoming tide. The water at this site was generally murky with visible suspended sediment and lower clarity than the other two sites in the catchment on all sampling occasions.

The concentrations of *E. coli* were higher at this location than they were at the upstream bush site as contaminant sources are introduced by the surrounding pastoral land. Faecal source tracking showed birds and possums to be the main contaminant source during dry weather and ruminant animals, specifically cows, to be the main contaminant during wet weather. This is not surprising given the surrounding dairy farm, despite the area being planted and fenced off, and the current resource consent to discharge farm animal effluent to land associated with the property (see Appendix 4).

3.2.1.3 Urban (stream mouth) site observations

Figure 9: Pepe Stream – Urban (stream mouth) site (Site 10).

At the stream mouth sampling site of Pepe Stream (urban site), we saw that the stream itself and the surrounding reserve area were always popular recreation areas. We saw children swimming in the stream in both dry and wet weather conditions, with families picnicking on the stream banks or using the adjacent playground. The site was also popular with dog walkers and inhabited by many birds (seagulls and ducks) on each visit. This site differs to the other stream mouth sites in that there is a small tidal inlet between the pastoral site and the stream mouth site. This will influence the results as there is greater potential for dilution by the incoming and outgoing tide.

E. coli concentrations decreased at the stream mouth from the pastoral site, likely due to the increased dilution and tidal flushing taking place at this site (Figure 10). *E. coli* levels were relatively low during dry weather, however, they increased to exceed the recreational water quality guidelines after rainfall on both sampling occasions (Figure 11). FST identified a mixture of sources of contaminants after rainfall including ruminant animals, birds and possums (Table 3). The ruminant sources were the most dominant source of contamination as a result of the upstream dairy farming activities.

E. coli concentrations were higher during spring tides than they were during neap tides. This is likely due to the increased inundation of the surrounding reserve areas that can happen during these larger tides. Any addition of faecal bacteria from birds was not substantial enough to be detected by FST (Table 3). A second potential source could be from dogs, however, given that no canine markers were tested for in this investigation, we can only speculate. The previous survey in 2015 found no identifiable canine markers so it's unlikely that faecal contamination from dogs at this location is a significant issue.

Another contributing factor could be the formation of a salt plug at the stream mouth, where the larger volume of seawater moving into the stream mouth that occurs during a spring tide can trap or limit freshwater outputs causing contaminants to accumulate in the estuary (Shaha et al. 2016; Walanski 1986).

3.2.1.4 Summary

Overall water quality in the Pepe Stream catchment was highest in the upper catchment (bush) and lowest in the mid catchment, pastoral site. Water quality in this catchment was heavily affected by rainfall, with all sites exceeding the recreational water quality guidelines on all wet weather sampling occasions.

Table 3: Frequency of exceedances of the recreational water quality guidelines in the Pepe Stream Catchment, Tairua.

	Dry Weather	Wet Weather	Neap Tide	Spring Tide
Bush Site (Pepe Stream – upper)			NA	NA
Pastoral Site (Pepe Stream – mid)	 	  	NA	NA
Urban Site (Pepe Stream – lower)		  		

Green = no exceedances of the recreational water quality guidelines
Orange = a single exceedance of the recreational water quality guidelines
Red = two exceedances of the recreational water quality guidelines

 = avian sources detected
 = human sources detected
 = ruminant sources detected (cows)
 = ruminant sources detected (sheep)
 = possum sources detected

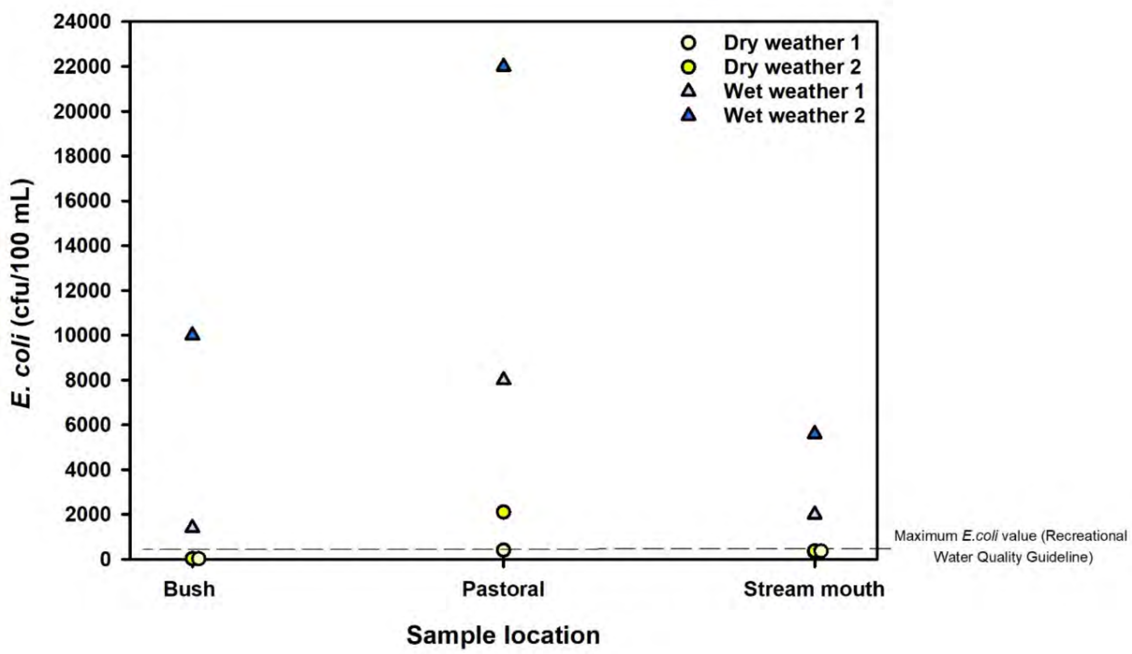
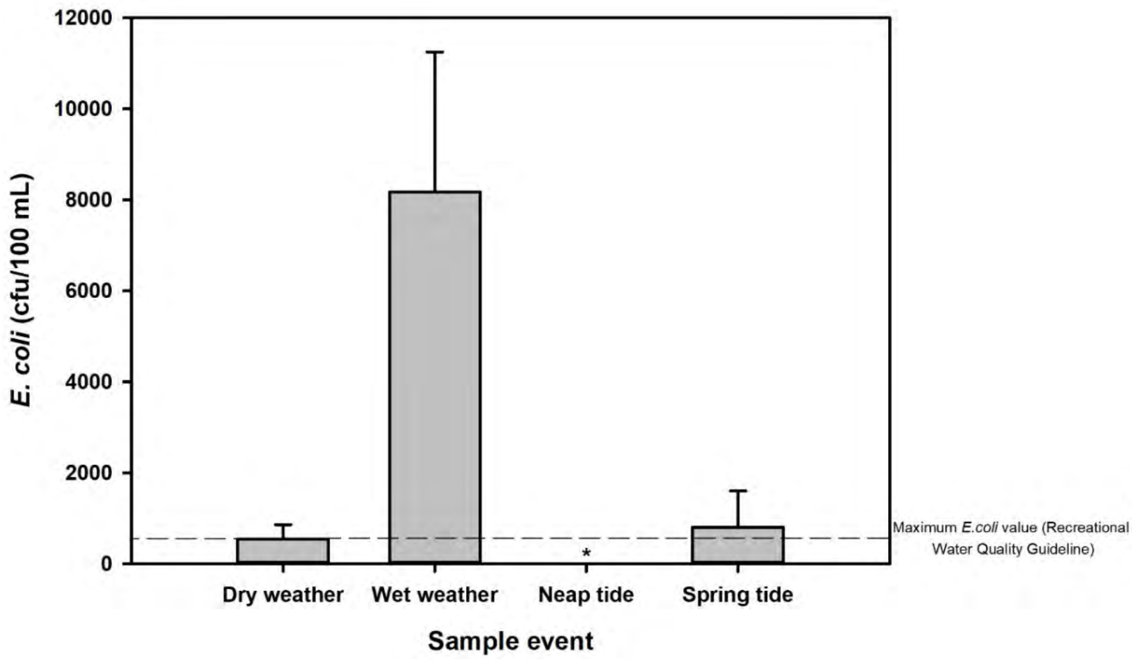


Figure 10: Concentrations of *E. coli* in all sample locations in the Pepe Stream catchment for two wet weather events and two dry wet weather events.



* Results were too low to be visualized on the graph (mean value = 2 cfu/100 mL)

Figure 11: Average concentrations of *E. coli* across the Pepe Stream catchment for all sample event types.

3.2.2 Taputapuatea Stream, Whitianga

3.2.2.1 Bush site observations

Figure 12: Taputapuatea Stream – Bush site (Site 9).

The bush site of Taputapuatea Stream is located down a steep bank covered with mostly rank grass[5]. The stream is located next to a farm where several cows were observed on most sampling occasions. The stream at this site was soft-bottomed and sediment stirred up easily, however, when undisturbed, the water clarity was high. The site was clear of debris and had some undercut banks supported by tree roots. The water at this site was relatively slow flowing and of overall high quality.

E. coli concentrations were within the recreational water quality guidelines during dry weather sampling, however, exceeded the recreational water quality guidelines on both wet weather sampling occasions. FST showed the likely sources of *E. coli* to be dominated by ruminant animals (cows), with some possum and avian sources as well in all samples tested.

[5] A collective term for grasses that have been left to grow out of control without cutting or weed management

3.2.2.2 Pastoral site observations

Figure 13: Taputapuatea Stream – Pastoral site (Site 8).

The mid-catchment site (pastoral site) of Taputapuatea Stream is located along a public walkway between the edge of the bush and the residential properties on the edge of the Whitianga Township. A margin of riparian planting with a width of at least 5 m borders the stream bank, which was waterlogged on the majority of sampling occasions. The site is tidally influenced and had poor clarity with visible suspended sediment on all occasions. We saw ducks in the stream on multiple sampling occasions.

The concentrations of *E. coli* were higher at this location than they were at the bush site as contaminant sources were introduced by the surrounding pastoral land. However, like the bush site, *E. coli* concentrations did not exceed the recreational water quality guidelines during dry weather. Exceedances occurred after rainfall with ruminant animals being identified as the main source of faecal contamination. One wet weather sample also identified possible avian and possum sources as well.

3.2.2.3 Urban (stream mouth) site observations

Figure 14: Taputapuatea Stream – Urban (stream mouth) site (Site 7).

The stream mouth sampling site of Taputapuatea Stream (urban site) is a popular recreation area and is adjacent to a large reserve area with a boardwalk. The stream mouth itself was popular with children swimming and wading, kayakers, and stand-up paddle boarders. We also saw people walking their dogs along the path in both dry and wet weather conditions and there were many seagulls (30+) sitting on the banks of the stream or in the water on each site visit.

There was a slight exceedance of the recreational water quality guidelines on the first wet weather sampling occasion and a substantial exceedance on the second wet weather sampling occasion (Figure 15). FST indicated ruminant sources, with possible possum and avian sources as well (Table 4).

We also saw a small increase in *E. coli* concentrations (but no exceedance of the recreational water quality guidelines) during the second spring tide sampling event that took place after heavy rainfall (Figure 16). FST indicated very weak potential human sources. Given the extensive amount of rain that occurred prior to this spring tide sampling occasion and the saturation of local soils that occurred, there is a possibility that the increased volumes of stormwater could have resulted in overflows from wastewater networks into the stormwater system, potentially contributing human sources of bacteria.

E. coli concentrations were, on average, higher during a spring tide than during a neap tide. This is likely due to the tidal inundation of the surrounding reserve areas washing the contaminants into the waterway.

3.2.2.4 Summary

Overall, water quality in the Taputapuatea Stream catchment was highest in the upper bush catchment and lowest in the mid catchment, pastoral site. Water quality in this catchment was heavily affected by rainfall, with all sites exceeding the recreational water quality guidelines on all wet weather sampling occasions.

Table 4: Frequency of exceedances of the recreational water quality guidelines in the Taputapuatea Stream Catchment, Whitianga.

	Dry Weather	Wet Weather	Neap Tide	Spring Tide
Bush Site (Taputapuatea Stream – upper)			NA	NA
Pastoral Site (Taputapuatea Stream – mid)			NA	NA
Urban Site (Taputapuatea Stream – lower)				

Green = no exceedances of the recreational water quality guidelines
Orange = a single exceedance of the recreational water quality guidelines
Red = two exceedances of the recreational water quality guidelines

 = avian sources detected
 = human sources detected
 = ruminant sources detected (cows)
 = ruminant sources detected (sheep)
 = possum sources detected

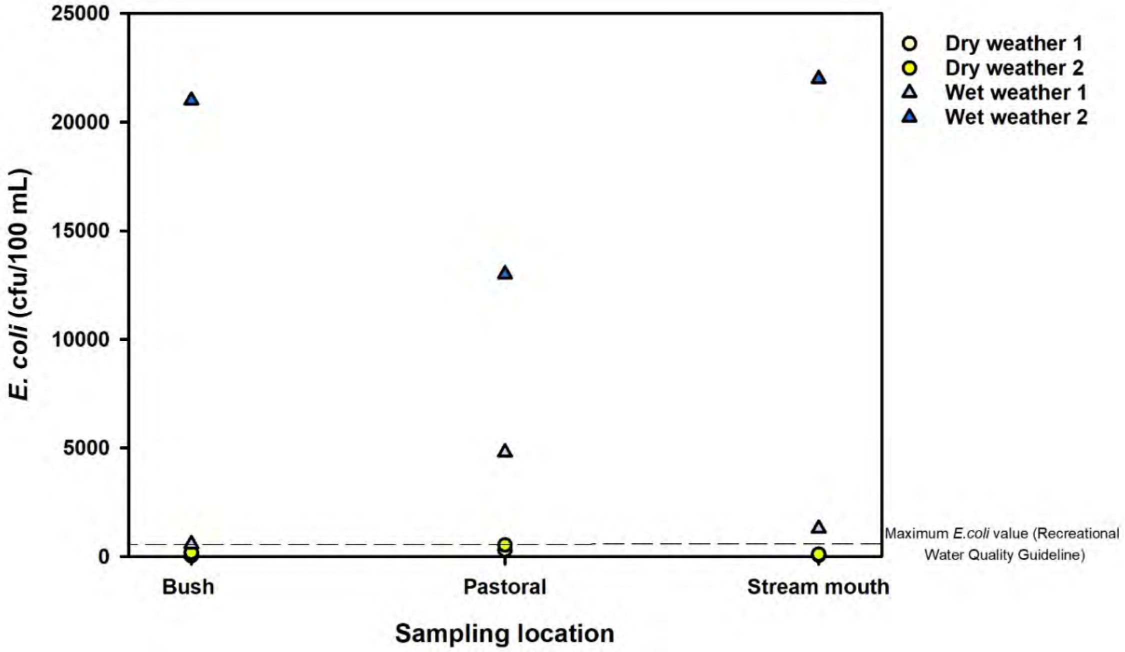


Figure 15: Concentrations of *E. coli* in all sample locations in the Taputapuatea Stream catchment for two wet weather events and two dry wet weather events.

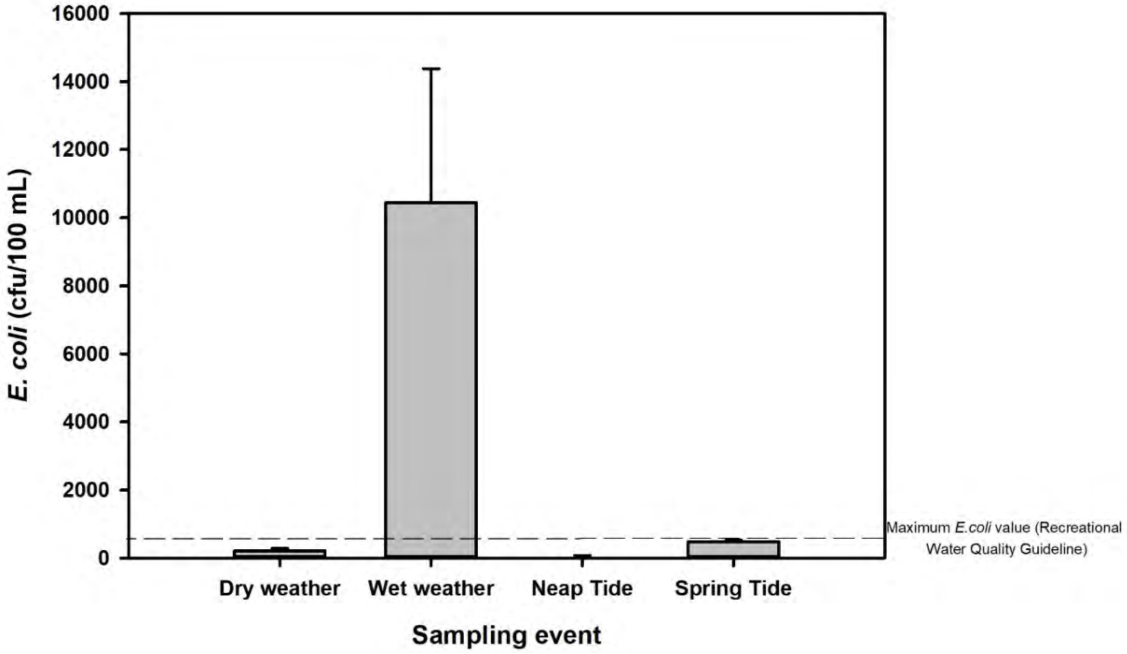


Figure 16: Average concentrations of *E. coli* across the Taputapuatea Stream catchment for all sample event types.

3.2.3 Kuaotunu Stream, Kuaotunu

3.2.3.1 Bush site observations

Figure 17: Kuaotunu Stream – Bush site (Site 6).

The upper catchment (bush site) of Kuaotunu Stream is next to the main road down a steep bank. Large trees line the stream bank providing a good amount of shade. The stream has a stony bottom with slightly faster flow rates than the other sites. The water at this site was of high clarity. We also saw riffles at this site, which likely contributed to the high levels of dissolved oxygen in the water on all sampling occasions.

E. coli concentrations exceeded the recreational water quality guidelines once on a dry sampling occasion and after both rainfall events. FST showed ruminant animals to be the dominant source with a small contribution from avian sources in the dry sample. Additionally, FST identified possum sources in the wet samples.

3.2.3.2 Pastoral site observations

Figure 18: Kuaotunu Stream – Pastoral site (Site 5).

The mid-catchment site (pastoral site) was on the Waitaia Stream, a tributary of the Kuaotunu Stream. On two occasions, we observed small amounts of food waste (mostly oranges and fish carcases) in the stream. Regenerating bush lined the stream banks providing good shade.

The water was very shallow at this site and the stream was slow flowing. Water clarity was significantly better at this site than at pastoral sites in other catchments. Unlike the other pastoral sites monitored, this site was not tidally influenced. In the other catchments, the pastoral site was located on the main stream just before the town, however, in this catchment, the site was located on a tributary of the main stream and was surrounded by residential properties

E. coli concentrations exceeded the recreational water quality guidelines on one dry occasion and on both wet weather occasions. Possum was the main source identified with possible avian sources in dry weather. Ruminant animals were identified during wet weather. This catchment has the largest percentage of land use occupied by bush, it is therefore not surprising that we would see possum as a dominant source of contamination in this catchment (see Appendix 4).

3.2.3.3 Urban (stream mouth) site observations

Figure 19: Kuaotunu Stream – Urban (stream mouth) site (Site 4).

The mouth of Kuaotunu Stream is in the centre of the small Kuaotunu Township. A grassed reserve area borders the stream and is adjacent to a carpark. The ease of access to the stream mouth and the closeness to the shops and car park means that this site is very popular for contact recreation. When sampling, we often saw children swimming, wading, and kayaking and small boats were moving up the stream. There were also dogs being walked on the grassed banks on several occasions. A thick scum of sea foam covered the surface of the stream on one occasion during a neap tide sampling event.

E. coli concentrations were higher at this site than either of the other sites in this catchment. The recreational water quality guidelines were exceeded on one dry weather and one spring tide occasion, as well as on both wet weather occasions.

This was the only stream mouth in all catchments where we didn't see a reduced *E. coli* concentration as a result of dilution from tidal flushing. This could be because the main sources of contamination at this site are coming from lower down in the catchment (downstream of the bush and pastoral sites) and not mainly from pastoral sources. Alternatively, this site is relatively elevated which could influence tidal flushing of the stream mouth, limiting the dilution of contaminants in comparison to the other stream mouths monitored.

FST identified possum and ruminant sources in wet and dry samples. There were weak indications of human sources of contamination during one neap tide sampling.

3.2.3.4 Summary

Water quality in this catchment was heavily affected by rainfall, with all sites exceeding the recreational water quality guidelines on all wet weather sampling occasions, regardless of land use type (Figure 20). The bush and pastoral sites had elevated *E. coli* contamination during dry weather on one sampling occasion (Table 5). *E. coli* concentrations at the stream mouth were higher during a spring tide than a neap tide (Figure 21).

There were large pH fluctuations throughout the Kuaotunu Stream catchment. The saturation of dissolved oxygen in the water was significantly lower at Kuaotunu's pastoral site than in the other two sites in this catchment, most likely due to the shallowness of the water and the slow flow of the water at this site in comparison to the other pastoral sites.

Table 5: Frequency of exceedances of the recreational water quality guidelines in the Kuaotunu Stream Catchment, Kuaotunu.

	Dry Weather	Wet Weather	Neap Tide	Spring Tide
Bush Site (Kuaotunu Stream – upper)			NA	NA
Pastoral Site (Kuaotunu Stream – mid)			NA	NA
Urban Site (Kuaotunu Stream – lower)				

Green = no exceedances of the recreational water quality guidelines
Orange = a single exceedance of the recreational water quality guidelines
Red = two exceedances of the recreational water quality guidelines

 = avian sources detected  = human sources detected

 = ruminant sources detected (cows)  = ruminant sources detected (sheep)

 = possum sources detected

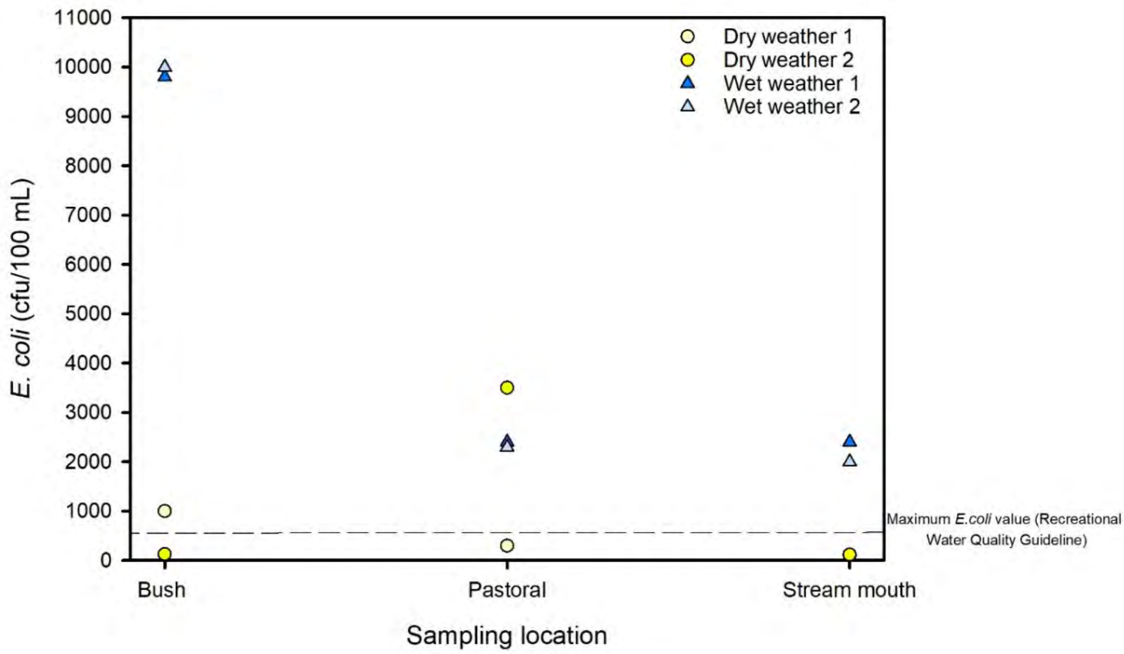


Figure 20: *E. coli* concentrations at all sample locations in the Kuaotunu Stream catchment for two wet weather events and two dry wet weather events.

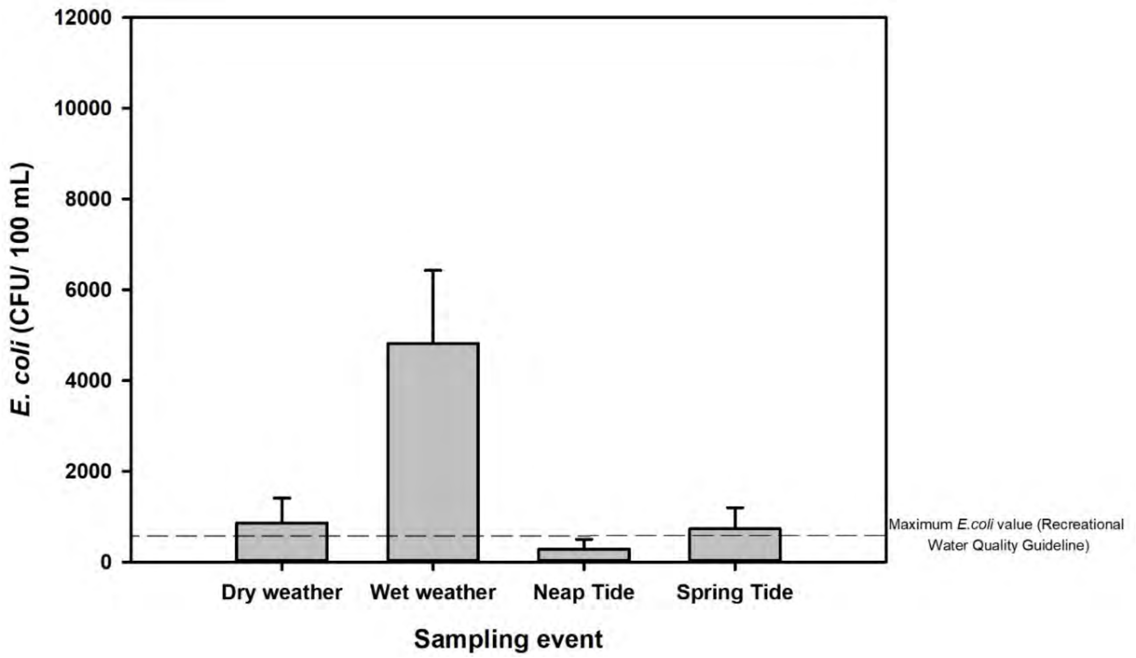


Figure 21: **Average concentrations of *E. coli* across the Kuaotunu Stream catchment for all sample event types.**

3.2.4 Stewart Stream, Opito Bay

3.2.4.1 Bush site observations

Figure 22: Stewart Stream – Bush site (Site 3).

The upper catchment (bush site) of Stewart Stream was fenced off and well shaded by bush canopy cover. The stream was shallow and relatively slow flowing, well oxygenated, and temperatures were always within acceptable ranges. Water clarity was also higher than the other sites in the catchment. The site was down a steep bank and had a riparian margin of approximately 2 m on the fenced side and the other stream bank was bordered by native bush.

E. coli concentrations exceeded the recreational water quality guidelines only after rainfall. FST was carried out on one wet and dry sample, however, no sources faecal were detected. This indicates that the contamination was not likely to be from a fresh faecal source.

3.2.4.2 Pastoral site observations

Figure 23: Stewart Stream – Pastoral site (Site 2).

The mid-catchment site (pastoral site) of Stewart Stream is in the middle of a sheep and beef farm, with cows being observed close by on all site visits. The majority of the stream is well fenced off which inhibited stock access to the stream. The water at this site was noticeably coloured with dissolved organic matter and had poor clarity on each sampling occasion. This site has no riparian margin or shading. This lack of shading combined with the slow flow meant that the water temperature was always very high, especially during the dry weather sampling occasions.

The site had the lowest measured dissolved oxygen saturation of all sites in this investigation. The low flow and high water temperatures are likely key factors influencing the amount of oxygen dissolved in the water.

E. coli concentrations increased from the bush site upstream as new contaminant sources are introduced by the surrounding pastoral land. *E. coli* concentrations exceeded the recreational water quality guidelines on one dry sampling day as well as on both rainfall occasions. FST showed ruminant sources to be dominant with small inputs from birds during dry weather.

3.2.4.3 Urban (stream mouth) site observations

Figure 24: Stewart Stream – Urban (stream mouth) site (Site 1).

At the stream mouth sampling site of Stewart Stream (urban site), the stream itself and the surrounding reserve area were popular with campers and kayakers. There were no dogs present on any site visits, but there were ducks on occasion and large groups of seagulls sitting on the sandbar at the far end of the stream mouth on most sampling occasions. We also saw dotterels on several occasions on the sand bar. A riparian margin of flaxes provided a small buffer zone and also limited access to the stream banks on one side.

E. coli concentrations were lower at the stream mouth than they were at the pastoral site. This is likely a result of the tidal flushing at this site. *E. coli* concentrations exceeded the recreational water quality guidelines on one dry sampling occasion, both wet weather occasions, and during both spring tides. FST identified ruminant sources in the wet weather samples but at levels inconsistent with fresh inputs, that is, *E. coli* concentrations were relatively high, but FST results were low.

3.2.4.4 Summary

Overall, water quality in the Stewart Stream catchment was highest in the upper catchment (bush) and lowest in the mid catchment, pastoral site (Figure 25). The stream mouth site was also more highly oxygenated than the other stream mouth sites. As with the other catchments, all sites were highly influenced by rainfall, with concentrations of *E. coli* exceeding the recreational water quality guidelines on both wet weather sampling occasions (Table 6, Figure 26).

Table 6: **Frequency of exceedances of the recreational water quality guidelines in the Stewart Stream Catchment, Opito Bay.**

	Dry Weather	Wet Weather	Neap Tide	Spring Tide
Bush Site (Stewart Stream – upper)	**No source identified**	**No source identified**	NA	NA
Pastoral Site (Stewart Stream – mid)			NA	NA
Urban Site (Stewart Stream – lower)				**No source identified**

Green = no exceedances of the recreational water quality guidelines
Orange = a single exceedance of the recreational water quality guidelines
Red = two exceedances of the recreational water quality guidelines

 = avian sources detected

 = human sources detected

 = ruminant sources detected (cows)

 = ruminant sources detected (sheep)

 = possum sources detected

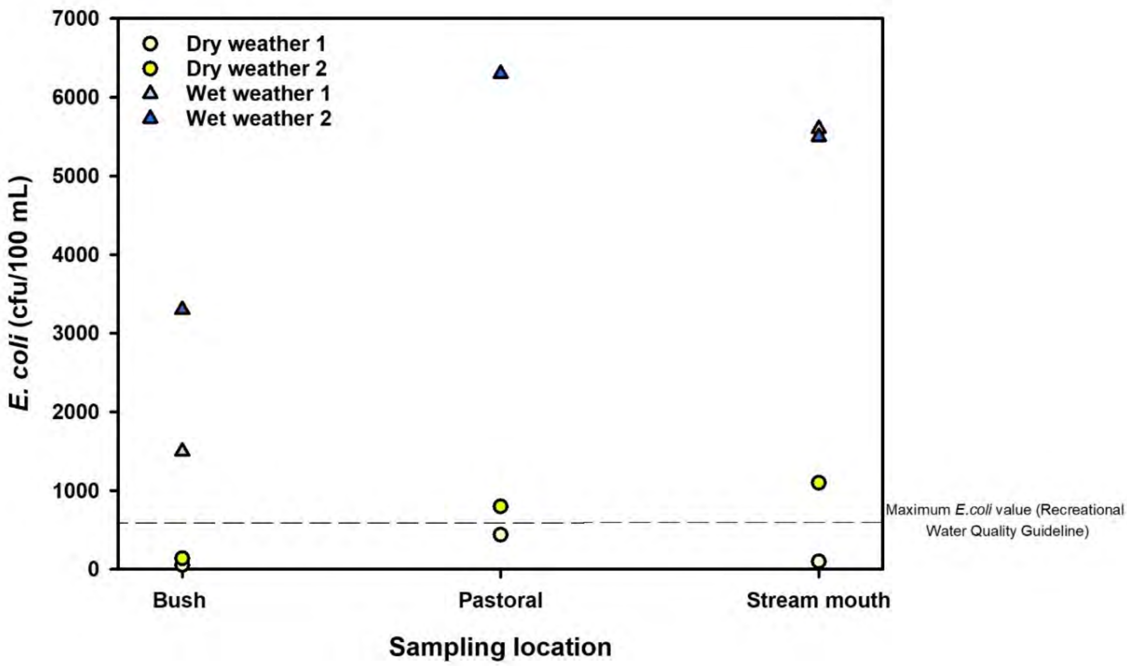


Figure 25: ***E. coli*** **concentrations in all sample locations in the Stewart Stream catchment for two wet weather events and two dry wet weather events.**

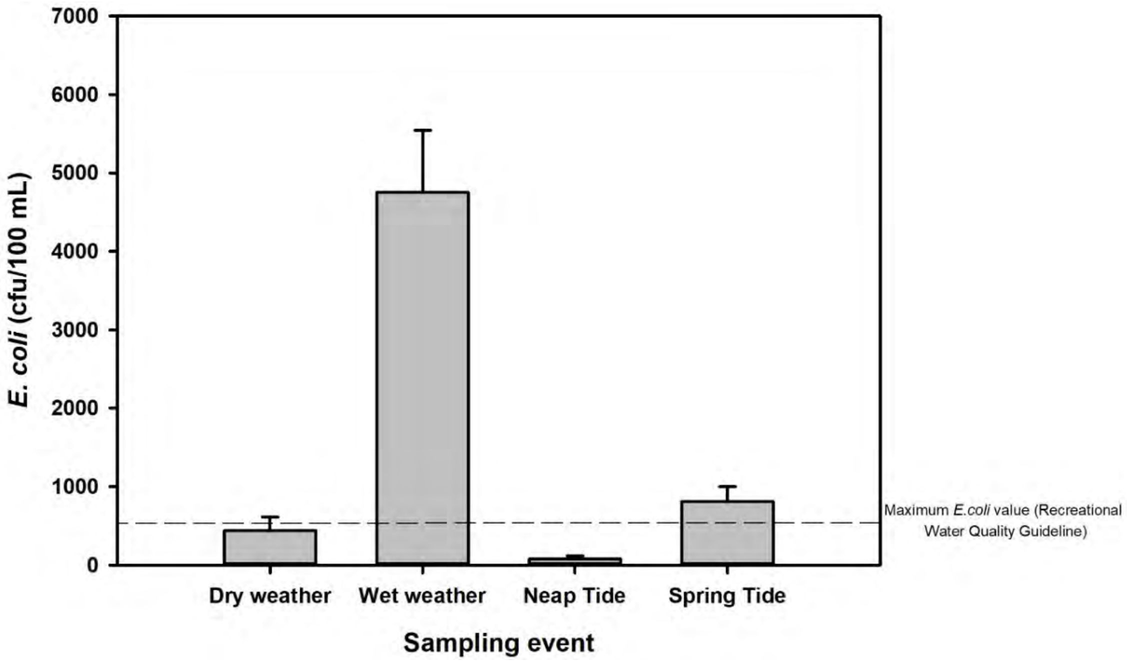


Figure 26: **Average *E. coli* concentrations across the Stewart Stream catchment for all sample event types.**

4 Conclusions

The more we investigate the state of water quality in our coasts and estuaries, the more opportunities there are to identify water quality issues, particularly excess nutrients, sediment, and bacteria. The sources of these contaminants are rarely derived within the estuaries themselves; in most cases, we need to identify diffuse sources in the catchment that are flushed into estuaries via streams and rivers following rainfall or during the flooding of low-lying land caused by spring tides, using approaches and techniques such as those used in this investigation.

Overall, the findings from this report provide clear evidence that reinforces our understanding of faecal contamination in waterways — faecal bacteria are highest following rainfall and, to a lesser extent at stream mouths, during spring tides. The levels of faecal bacteria are also influenced by the surrounding land use.

The uniqueness of this investigation in the Waikato region is in its approach: combining event-based sampling along a stream to isolate sub-catchments and land use, water quality measurements, and faecal source tracking. This approach provides results that point clearly towards how the levels of faecal bacteria are influenced by rainfall, tides, and the surrounding land use. This can guide catchment management actions towards the most efficient use of resources to address the issues around diffuse contaminant sources entering waterways.

In this study, water quality was typically best in the upper bush catchment sites. Following heavy rainfall, however, these bush sites typically had faecal bacteria concentrations that exceeded the recreational water quality guidelines, which means they were unsuitable for swimming during these times. This was somewhat surprising considering the absence of human activities upstream.

During wet weather, we typically measured the greatest increase in faecal bacteria between the upper-catchment bush site and the mid-catchment pastoral site. The levels of faecal bacteria were often lower at the stream mouth sites than at the pastoral sites. This indicates that the greatest source of faecal contamination in these catchments during rainfall was the pastoral land. This is despite the majority of stream banks being fenced off from stock and well planted, as is best farming management practice.

All contaminants introduced into the waterway, regardless of their source within the catchment, will eventually make their way via the stream mouth and out to the ocean. This makes the stream mouth particularly susceptible to elevated contaminant levels. It's important for Council to remain aware of the water quality at these stream mouth locations because are they are popular swimming locations, particularly with young children and families. Furthermore, it may be necessary to have a greater public awareness of the risks of swimming in our coastal waters following heavy rainfall.

5 Recommendations

The approach of combining event-based sampling at multiple locations along the stream and conducting water quality analyses and faecal source tracking has provided results that are suitable for informing potential catchment management actions if deemed necessary. This is an improvement on the findings presented in the 2015 snapshot report, which identified water quality issues in the stream mouths, at times, but was not able to narrow down the many potential sources of contaminants within the catchment. There are, however, a few limitations with this approach that could be improved with the further development of faecal source tracking methods.

At this stage, it's not possible to compare faecal source markers with each other; that is, it's not possible to determine the proportion of faecal contamination that was contributed by different animals or whether one animal has contributed more than another. This makes it difficult to address the question of which animals are responsible for the greatest amount of faecal contamination in our waterways using the FST approach on its own. This reinforces the need to implement a strategic sampling design and use multiple approaches to build a picture of what is happening.

There have been recent developments with the ruminant marker such that results can be placed into one of three categories to describe the percentage contribution of ruminant faecal bacteria relative to the total amount. Where possible, the laboratory reported the numerical value of the ruminant marker and then categorised the result as <1%, 1–50%, or 50–100% of the total faecal bacteria. Reporting results in this way makes it very simple to communicate. Extending this type of reporting to other markers would be highly valuable, especially the human marker(s).

A limitation of the FST approach that still exists since the 2015 investigation is that brushtail possums and, to a lesser extent, a few other animals, cause false-positives for the primary human marker. This is particularly an issue in catchments with large proportions of native bush such as those found throughout the Coromandel. In this study, the laboratory tested for two human markers and only confirmed a potential human source if both markers were detected. This can make communicating results more complex as the more sensitive human marker is consistently detected, likely because of the number of possums (and other animals that can trigger this marker) in the catchments of interest. Furthermore, this also reduces the sensitivity for detecting human sources as the second human marker is less sensitive than the first.

The risk to human health from faecal contamination in the water is dependent on the source of the contamination. For example, the risk to human health is greater from ruminant animal or human faecal sources than it is from bird or pig faecal sources (Soller et al. 2010). This could mean that even though faecal bacteria levels exceeded the recreational guideline values at the bush sites after rainfall, there is a possibility that the risk to human health was less than the guidelines suggest. If the levels of faecal contamination coming out of native/exotic bush become problematic or of concern to the community, further investigation should be carried out to determine whether the recreational water quality guideline values for *E. coli* are representative of actual risk to human health.

The approach used in this study is suitable for targeted investigations to provide clear information about where contamination is coming from within a catchment and what the contaminant sources are likely to be. The high cost of this approach, however, will limit the frequency that it can be applied. Continued development of the faecal source tracking capabilities will further increase the specificity of the results. This will enable clearer guidance to catchment managers to assess the source and extent of contaminants that are detected in our coastal stream mouths at times.

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Appendix 1 – Detailed observations in each catchment

Pepe Stream (Tairua)

Site 10 (Mouth)

Overall, the water was one of the best oxygenated out of all the sites monitored. Nutrient concentrations in the water were within ANZECC guidelines but the site was susceptible to *E. coli* concentrations that exceeded the recreational water quality guidelines after rainfall and during spring tides weather. Two main reasons for increases in faecal bacteria have been identified. The first being contributions from the bush with possum and avian sources, and a second more dominant source being ruminant sources from the pastoral land use in the mid catchment.

Physical parameters

The temperature at this site was generally warm (19–26°C) and strongly influenced by the nearby ocean (high salinity). The water was well oxygenated on all sampling occasions. pH levels were below the ANZECC guideline levels on one wet weather monitoring occasion.

Microbiological parameters

E. coli levels were very low during times of dry weather but increased to exceed the recreational water quality guidelines after rainfall, where concentrations of *E. coli* were up to 18 times greater than the recreational water quality guideline value. MST analysis found a mixture of sources of contaminants after rainfall including birds and possums, but ruminant sources were the most dominant source of contamination at 50–100% contribution. The influence of neap and spring tides on concentrations of *E. coli* at the stream mouth was also apparent, with *E. coli* levels more likely to be higher during a spring tide than a neap tide. This could be due to the increased tidal inundation of the surrounding reserve areas that can happen during these larger tides

Nutrients

All nutrient concentrations were within the ANZECC guidelines during wet weather sampling. Some minor exceedances of ammoniacal-N and TSS occurred during dry weather conditions but concentrations were within ranges that are unlikely to cause any adverse effects (e.g., nuisance algae growth).

Site 11 (Mid)

Overall the water quality at this site was moderate during dry weather and poor during wet weather. There were particularly large increases in faecal bacteria during rainfall, mostly attributed to ruminant sources.

Physical parameters

The water temperature at this site was fairly consistent, ranging from 18–22°C. Salinity was generally high at this site as well due to the tidal influence. The dissolved oxygen saturation fell just below 80% on one wet weather occasion but otherwise, oxygenation was well above 80% on all other occasions. pH also exceeded the ANZECC guidelines after one rainfall event.

Microbiological parameters

The measured *E. coli* concentration exceeded the recreational water quality guidelines on three out of four sampling occasions. The two greatest exceedances (up to~40 times greater than the guideline value) were following rainfall. Faecal source tracking showed birds and possums (10–50%) to be the main contaminant source during dry weather and ruminant animals (50–100%) during wet weather.

Nutrients

Minor exceedances of nitrate-N + nitrite-N, Dissolved reactive phosphorus and ammoniacal-N were noted during dry weather sampling. Nitrate-N + nitrite-N concentrations were also elevated during wet weather sampling.

Site 12 (Bush)

Overall, the water quality at this site was high. Elevated levels of *E. coli* were only seen during heavy rainfall, which is to be expected in these water types.

Physical parameters

The water at this site was always well oxygenated (>80 %) and the water temperature was always within acceptable ranges. On one occasion after heavy rainfall, the pH exceeded the ANZECC guideline value.

Microbiological parameters

E. coli concentrations were within the recreational water quality guidelines during dry weather sampling. *E. coli* concentrations only exceeded the recreational water quality guidelines following rainfall (up to ~10 times greater than the guideline value). Faecal source tracking showed the likely source of the increased *E. coli* to be from possums

Nutrients

Nutrient levels were all within ANZECC guidelines on all sampling occasions.

Taputapuatea Stream (Whitianga)

Site 7 (Mouth)

Overall, the water was well oxygenated at this site. Nutrient levels tended to be elevated at this site especially after rainfall and the site was susceptible to *E. coli* concentrations that exceeded the recreational water quality guidelines in dry and wet weather conditions.

Physical parameters

Dissolved oxygen at this site was generally good and exceed 80% on all occasions except one dry weather sampling event where DO was only 28%. The temperature at this site was generally warm and always exceeded 20°C and was strongly influenced by the nearby ocean (high salinity). On one occasion after heavy rainfall, the pH exceeded the guideline value.

Microbiological parameters

E. coli concentration exceeded the recreational water quality guidelines at this location on at least one occasion for each sampling event (dry and wet weather, spring and neap tides).
The greatest *E. coli* concentrations were measured during wet weather sampling and were approximately 4-5 times greater than the recreational water quality guideline value. During wet weather, there were moderate to high contributions of faecal bacteria from ruminant animals (10–50% and 50–100%) with potential canine, possum and avian sources at lower levels.

E. coli concentrations were slightly increased during spring tides compared to neap tides, however, the recreational water quality guidelines were not exceeded on any tide sampling occasions.

Nutrients

Nutrient levels tended to be elevated at this site especially after rainfall, with a minor exceedance of the ANZECC guidelines measured for nitrogen. The concentrations seen however were within ranges that are unlikely to cause any adverse effects (e.g., nuisance algae growth).

Site 8 (Mid)

Overall, the water quality at this site was moderate. Nutrient levels tended to be relatively high after rainfall and levels of dissolved oxygen low, which, at times, may act as a stressor to animals living there or passing through. *E. coli* concentrations were typically within the recreational water quality guidelines during dry weather.

Physical parameters

The dissolved oxygen saturation in the water was particularly low on most sampling occasions — being less than 80% on three out of four monitoring occasions. The water temperature at this site was also highly variable, ranging from 18–28°C. On one occasion after heavy rainfall, the pH exceeded the ANZECC guideline value.

Microbiological parameters

The concentrations of *E. coli* were higher at this location than they were at the bush site as new contaminant sources were introduced by the surrounding pastoral land. However, like the bush site, no *E. coli* exceedances were observed during dry weather. Exceedances occurred after rainfall, with the highest exceedance being >20 times the guideline value. Ruminant bacteria had a moderate contribution (10–50%) during one of the both wet weather periods, with a smaller contribution (1–10%) during the dry weather results. One wet weather sample and one dry weather sample also identified possible avian and possum sources as well.

Nutrients

All nutrient concentrations were within the ANZECC guidelines during dry weather samples and one wet weather sampling event. Nitrogen and phosphorous levels exceeded guidelines during the second wet weather event, with phosphorous levels being approximately three times greater than the guideline.

Site 9 (Bush)

Overall the water quality at this site was well oxygenated and had a temperature within the range suitable for aquatic life. Elevated levels of *E. coli* were only seen during heavy rainfall.

Physical parameters

The water at this site was always well oxygenated (>80 %) and the water temperature was always within ANZECC guideline ranges. As with the other sites monitored in the catchment, pH levels exceeded the ANZECC guidelines following rainfall on one occasion.

Microbiological parameters

E. coli concentrations only exceeded the recreational water quality guidelines following rainfall. One exceedance was significant with concentrations being 40 times greater than the guideline value. Microbial source tracking showed that ruminant sources of contamination dominated (10–50%), with both samples tested also showing avian and possum sources.

Nutrients

One minor exceedance of total nitrogen was recorded (0.59 g/m^3) on one of the dry weather monitoring occasions. All other nutrients were within the ANZECC guidelines on all other sampling occasions.

Kuaotunu River (Kuaotunu)

Site 4 (Mouth)

Overall, the water quality at this site was moderate. The elevated temperatures and low dissolved oxygen at times may act as a stressor to animals living there or passing through. This is one of the main swimming locations along the Kuaotunu River and *E. coli* concentrations were typically within the recreational water quality guidelines making this site usually suitable for swimming, excluding during and following rainfall.

Physical parameters

The water temperature at this site was often greater than 20°C and was usually dominated by oceanic water. Dissolved oxygen dropped as low as ~30% on occasion, which is far below the guideline value of 80%. This could be a result of many factors, including the biological breakdown of sediments, low water movement, and high temperatures.

Microbiological parameters

E. coli concentrations exceeded the recreational water quality guideline on both wet weather sampling occasions (~18 times higher than the guideline value). Microbial source tracking showed a moderate (10–50%) contribution from ruminant bacteria on the first sampling occasion and a high (50–100%) contribution of ruminant bacteria on the second sampling occasion. Avian contributions were only detected on one occasion and an unquantifiable contribution from possums was detected on both occasions.

E. coli concentrations also exceeded the guideline on one of two dry weather sampling occasions (~2 times higher than the guideline value), and on one of two spring tide sampling occasions (~2 times higher than the guideline value). The dry weather samples had contributions from birds and a low contribution (1–10%) from ruminant animals. During spring tides, there was a moderate (10–50%) contribution from ruminant animals, a small contribution from birds and an unquantifiable contribution from possums.

Nutrients

Nutrient concentrations were typically within the ANZECC guideline values. Most exceedances were measured during wet weather sampling and were within ranges that are unlikely to cause any adverse effects (e.g., nuisance algae growth).

Site 5 (Mid)

Overall, the water quality at this site was moderate. In addition to faecal bacteria exceeded the recreational water quality guidelines during rainfall, as is expected, faecal bacteria was also high on one dry sampling occasion. From the range of sources tested, birds were the most likely source of this additional contamination on this sampling occasion.

Physical parameters

The water at this site was always well oxygenated (>80 %) and the water temperature was always within acceptable ranges. On one occasion, the pH exceeded the ANZECC guideline value by about 0.3 units (~pH 9.3).

Microbiological parameters

E. coli concentrations exceeded the recreational water quality guideline on three out of four sampling occasions. This included one exceedance during dry weather sampling that was higher (~6 times higher than the guideline value) than during wet weather sampling (~4 times higher than the guideline value).

In the dry weather sample that exceeded the guideline value, microbial source tracking identified elevated faecal sources from birds (avian GFD marker) and an unquantifiable contribution from possums. There was no detected contribution from ruminant animals or humans.

Microbial source tracking results were markedly different for the two wet weather events. In the first wet weather sample, microbial source tracking identified a contribution from birds and an unquantifiable contribution from possums. In the second wet weather sample, microbial source tracking identified a moderate (10–50%) contribution from ruminant animals and an unquantifiable contribution from possums but no contribution from birds. No human sources were detected in any samples.

Nutrients

Nutrient concentrations were always within the ANZECC guideline values.

Site 6 (Bush)

Overall, the water quality at this site was high. Exceedances of faecal bacteria and nutrients were typically only seen during rainfall events, which is to be expected in these water types.

Physical parameters

The water at this site was always well oxygenated (>80 %) and the pH and temperature were always within ANZECC guideline ranges.

Microbiological parameters

E. coli concentrations were within the recreational water quality guidelines during dry weather sampling. During wet weather sampling, however, *E. coli* concentrations exceeded the guideline value by about 2–4 times. Microbial source tracking showed lower concentrations of faecal bacteria than *E. coli* and enterococci indicators, which suggests it may not be a typical fresh faecal source. In the wet weather samples, tracking identified a moderate contribution (10–50%) from ruminant animals, a very small contribution from birds, and an unquantifiable contribution from possums. No human sources were detected in any samples.

Nutrients

Most of the time, nutrient concentrations were within ANZECC guideline values. On separate wet weather sampling occasions, total phosphorus and dissolved reactive phosphorus exceeded their guideline values. These exceedances were relatively minor and unlikely to have any adverse effects (e.g., nuisance/excessive algal growth).

Stewart Stream (Opito Bay)

Site 1 (Mouth)

Overall, the water was well oxygenated and the nutrient concentrations in the water were within ANZECC guideline ranges. This site was susceptible to *E. coli* concentrations that exceeded the recreational water quality guidelines on at least one of each sampling event (wet and dry weather, spring and neap tides); the reason for the increase in faecal bacteria is not clear. There was a small contribution from ruminant animals and birds, but in general, the microbial source tracking results indicated a lower level of faecal contamination the *E. coli*. This likely indicates that much of the faecal bacteria was not from a fresh source. Effluent seepage from septic tank disposal fields could possibly be a source.

Physical parameters

The temperature at this site was generally warm (20–26 °C) and strongly influenced by the nearby ocean (high salinity). The water was well oxygenated on all but one occasion, which was during wet weather.

Microbiological parameters

E. coli concentration exceeded the recreational water quality guidelines at this location on at least one occasion for each sampling event (dry and wet weather, spring and neap tides).

The greatest *E. coli* concentrations were measured during wet weather sampling and were about 10 times greater than the recreational water quality guideline value. There was a moderate contribution of faecal bacteria from ruminant animals (10–50%) but the remainder is unknown. Microbial source tracking indicated lower levels of faecal bacteria than the *E. coli* measurements, which indicates that it was likely not a typical fresh source of bacteria.

E. coli concentrations were slightly above the guideline value during spring tides (1.1–1.6 times greater than the guideline value) but the source of the contamination is unknown. On one occasion, there was a very weak signal that human contamination may have been present.

On one dry sampling occasion, the *E. coli* concentration was twice the guideline value. There was a low contribution from ruminant animals (10–50%) and from birds. Similar to other samples within this catchment, microbial source tracking indicated lower levels of contamination than *E. coli*, indicating that this was likely not a fresh source of faecal bacteria.

Nutrients

All nutrient concentrations were within ANEZECC guidelines during dry weather sampling. During wet weather sampling, some minor exceedances were measured for nitrogen but their concentrations were within ranges that are unlikely to cause any adverse effects (e.g., nuisance algae growth).

Site 2 (Mid)

Overall the water quality at this site was moderate-high during dry weather. There were particularly large increases in faecal bacteria during rainfall, however, these were likely not typical fresh sources.

Physical parameters

The water temperature at this site was highly variable, ranging from 18–28°C. The dissolved oxygen saturation in the water was particularly low on each sampling occasion — less than 80% and as low as 53%. This could be a result of many factors, including the biological breakdown of sediments, low water movement, and high temperatures.

Microbiological parameters

The measured *E. coli* concentration exceeded the recreational water quality guidelines on three out of four sampling occasions. The two greatest exceedances (~12 times greater than the guideline value) were following rainfall. Ruminant bacteria had a moderate contribution (10–50%) during one of the wet periods, but not in the other. Microbial source tracking results were much lower than *E. coli*, which indicates that this was likely not a fresh source of faecal contamination.

The other exceedance was during dry weather when the *E. coli* concentration was 1.5 times greater than the guideline value. There was a moderate contribution (10–50%) from ruminant animals and a small contribution from birds.

Nutrients

All nutrient concentrations were within ANZECC guidelines during dry weather samples. During wet weather sampling, some minor exceedances were measured for nitrogen and phosphorus. The nutrient concentrations were within ranges that are unlikely to cause any adverse effects (e.g., nuisance algae growth).

Site 3 (Bush)

Overall, the water quality at this site was high. The water was suitable for swimming during dry weather. Elevated levels of *E. coli* were only seen during heavy rainfall.

Physical parameters

The water at this site was always well oxygenated (>80 %) and the water temperature was always within acceptable ranges. On one occasion, the pH exceeded the ANZECC guideline value by about 0.2 units (~pH 6.3).

Microbiological parameters

E. coli concentrations only exceeded the recreational water quality guidelines following rainfall (~3–6 times greater than the guideline value). Microbial source tracking results were much lower, which indicates that this was likely not a fresh source of faecal contamination.

Nutrients

Nutrient concentrations were typically within ANZECC guideline values. The only exceedances, total phosphorus, were measured during wet weather sampling and were within ranges that are unlikely to cause any adverse effects (e.g., nuisance algae growth).

Appendix 2 – Laboratory analysis methods

The following analyses were carried out on each water sample by Hill Laboratories, Hamilton.

	Freshwater		Marine	
Parameter	Method	Detection limit	Method	Detection limit
Total suspended solids	APHA 2540 D	3 g/m^3	APHA 2540 D – saline	3 g/m^3
Total nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N	0.05 g/m^3	Calculation: TKN + Nitrate-N + Nitrite-N	0.05 g/m^3
Total ammoniacal-N	APHA 4500-NH_3 F	0.010 g/m^3	APHA 4500-NH_3 F – saline	0.010 g/m^3
Nitrate-N + Nitrite-N	APHA 4500-NO_3^- I	0.002 g/m^3	APHA 4500-NO_3^- I - saline	0.002 g/m^3
Total Kjeldahl Nitrogen (TKN)	APHA 4500-N_{org} D	0.10 g m^3	APHA 4500-N_{org} D	0.10 g/m^3
Dissolved reactive phosphorus	APHA 4500-P E	0.004 g/m^3	APHA 4500-P E	0.004 g/m^3
Total phosphorus	APHA 4500-P B & E	0.004 g/m^3	APHA 4500-P B & E	0.004 g/m^3
Faecal coliforms	APHA 9222 D	1 cfu/100 mL	APHA 9222 D	1 cfu/100 mL
Eschericia coli	APHA 9222 G	1 cfu/100 mL	APHA 9222 G	1 cfu/100 mL
Enterococci	APHA 9230 C	1 cfu/100 mL	APHA 9230 C	1 cfu/100 mL

Appendix 3 – Summary data tables

Wet weather results

	Stewart Stream, Opito Bay			Kuaotunu Stream, Kuaotunu			Taputapuatea Stream, Whitianga			Pepe Stream, Tairua		
Round 1	Stream mouth	Pastoral	Bush	Stream mouth	Pastoral	Bush	Stream mouth	Pastoral	Bush	Stream mouth	Pastoral	Bush
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
pH	6.26	6.2	6.31	6.66	8.12	7.87	8.01	7.62	8.4	8.13	7.68	7.82
DO (%)	62.6	68.1	90.4	31.6	90.4	94.4	86.2	66.2	88.6	79.3	75	93
Temperature (°C)	20	18	16.6	18.7	16.7	16.9	22.6	19.3	17.3	18	17.5	16.2
Salinity (psu)	4.06	1.34	0.13	24.72	0.1	0.08	27.31	0.57	0.06	19.7	4.37	0.03
E.coli (cfu/100mL)	5600	6300	1500	9800	2400	2400	580	4800	1300	1400	8000	2000
Enterococci (cfu/100mL)	10000	9800	5500	10000	5000	5000	600	8100	3100	2400	9800	2200
Total faecal coliforms (cfu/100mL)	6400	6300	1500	10000	2400	2400	580	5900	1300	1400	8600	2300
TSS (g/m3)	25	26	5	6	< 3	3	6	4	< 3	8	3	< 3
Dissolved Reactive Phosphorous (g/m3)	0.006	0.006	0.02	0.014	0.012	0.024	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total P (g/m3)	0.028	0.028	0.04	0.043	0.026	0.032	0.014	0.019	0.007	0.011	0.014	0.012
Total N (g/m3)	0.56	0.53	0.29	0.3	0.18	0.27	< 0.3	0.3	0.19	< 0.3	0.21	0.12
Total Kjeldahl N (g/m3)	0.51	0.48	0.29	0.3	0.18	0.27	< 0.2	0.26	0.19	< 0.2	0.21	0.12
Total Ammoniacal - N (g/m3)	0.018	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.011	< 0.010
Nitrate-N + Nitrite-N (g/m3)	0.045	0.046	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.035	< 0.002	0.004	0.008	< 0.002
Date	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017	9/02/2017
Time	10:36am	10:08am	9:41am	11:08am	11:22am	11:35am	12:15pm	11:40am	11:15am	10:15am	9:50am	9:20am

Round 2												
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
pH	8.38	7.89	8.98	8.26	9.27	8	5.71	5.9	5.43	5.67	5.04	5.73
DO (%)	85.2	77.1	88.9	58	90.9	95	83.2	71.8	96.2	90.4	93	99.9
Temperature (°C)	21.2	19.1	18.1	19.6	18.2	15.2	20.3	18.6	17.9	19.6	17.6	17
Salinity (psu)	31.72	0.16	0.1	18.97	0.07	0.09	1.52	0.08	0.04	10.7	0.06	0.02
E.coli (cfu/100mL)	5500	6300	3300	10000	2300	2000	21000	13000	22000	10000	22000	5600
Enterococci (cfu/100mL)	6000	59000	5900	23000	5700	24000	29000	23000	5500	600	5500	1000
Total faecal coliforms (cfu/100mL)	5600	6300	3700	11000	2400	4000	22000	14000	23000	11000	23000	5700
TSS (g/m3)	27	105	76	18	8	12	26	35	28	11	9	5
Dissolved Reactive Phosphorous (g/m3)	< 0.004	< 0.004	0.008	0.012	0.006	0.01	0.022	0.013	< 0.004	0.004	0.004	< 0.004
Total P (g/m3)	0.029	0.059	0.054	0.066	0.034	0.05	0.091	0.116	0.03	0.014	0.02	0.007
Total N (g/m3)	0.3	0.5	0.37	0.6	0.26	0.31	0.78	0.84	0.26	<0.3	0.2	0.16
Total Kjeldahl N (g/m3)	0.3	0.45	0.35	0.5	0.22	0.28	0.5	0.59	0.25	<0.2	0.17	0.15
Total Ammoniacal - N (g/m3)	< 0.010	0.033	< 0.010	0.016	< 0.010	< 0.010	0.086	0.155	<0.01	<0.010	< 0.010	< 0.010
Nitrate-N + Nitrite-N (g/m3)	0.041	0.052	0.02	0.112	0.035	0.029	0.28	0.26	0.011	0.013	0.026	0.007
Date	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017	27/03/2017
Time	10:45AM	10:20AM	10:00AM	11:20AM	11:40AM	12:00PM	11:50AM	11:20AM	10:45AM	9:35AM	9:10AM	8:30AM

Dry weather results

	Opito Bay – Stewart Stream			Kuaotunu - Kuaotunu Stream			Whitianga - Taputaputea Stream			Tairua - Pepe Stream		
Round 1	Stream mouth	Pastoral	Bush	Stream mouth	Pastoral	Bush	Stream mouth	Pastoral	Bush	Stream mouth	Pastoral	Bush
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
pH	7.26	6.6	7.96	7.11	7.84	8.15	7.42	7.12	8.77	6.93	6.54	5.98
DO (%)	89	53.2	92.4	69.4	93.7	94.4	104.4	68.8	99.1	103.1	82.2	101.6

Temperature (°C)	25.8	28.2	17.4	19.8	17	17.2	23.9	26.5	18.4	31.8	20.2	16.1
Salinity (psu)	21.74	27.11	0.12	20.61	0.11	0.09	19.55	24.72	0.09	0.05	23.14	0.03
E.coli (cfu/100mL)	100	440	55	1000	300	110	38	300	57	26	400	330
Enterococci (cfu/100mL)	200	530	220	2200	2200	600	2	320	220	14	140	130
Total faecal coliforms (cfu/100mL)	110	440	55	1300	360	120	38	390	57	26	400	330
TSS (g/m3)	11.48	1.56	0.18	14.29	0.21	0.29	13.87	4.63	0.11	18.30	5.03	0.58
Dissolved Reactive Phosphorous (g/m3)	0.004	0.004	0.014	0.008	0.005	0.013	0.004	0.004	0.004	0.004	0.004	0.005
Total P (g/m3)	0.01	0.006	0.02	0.024	0.01	0.019	0.012	0.015	0.005	0.007	0.018	0.006
Total N (g/m3)	0.3	0.3	0.1	0.3	0.11	0.11	0.3	0.3	0.3	0.3	0.2	0.11
Total Kjeldahl N (g/m3)	< 0.2	< 0.2	< 0.10	< 0.2	< 0.10	< 0.10	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.10
Total Ammoniacal - N (g/m3)	0.01	0.01	0.01	0.024	0.01	0.01	0.012	0.022	0.01	0.018	0.026	0.01
Nitrate-N + Nitrite-N (g/m3)	0.004	0.005	0.004	0.008	0.002	0.002	0.005	0.022	0.002	0.002	0.006	0.002
Date	11.48	1.562	0.176	14.293	0.21155	0.2891	13.87	4.627	0.1096	18.2965	5.031	0.576
Time	12:35pm	12:00pm	11:15am	10am	9:20am	8:30am	2:40pm	3:00pm	3:30pm	1:45pm	12:45pm	12:00pm

Round 2												
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
pH	6.98	6.37	7.77	7.46	8.47	8.1	7.56	6.77	8.61	7.81	7.32	7.27
DO (%)	93.6	34.9	87.9	42.6	90.2	95.5	28.4	113.1	94.5	101.1	79.8	99.5
Temperature (°C)	25.4	22.2	18	22.1	18.2	18.8	24.1	27.9	19.4	19.1	22.1	17.3
Salinity (psu)	16.34	3.37	0.12	32.4	0.12	0.09	10.38	17.16	0.08	33.9	27.29	0.03
E.coli (cfu/100mL)	1100	800	140	130	3500	120	190	530	110	25	2100	370
Enterococci (cfu/100mL)	2400	230	540	240	1600	140	29	230	120	8	680	150
Total faecal coliforms (cfu/100mL)	1100	800	140	190	3500	150	360	930	130	26	2100	370
TSS (g/m3)	13	11	< 3	22	< 3	< 3	7	3	< 3	42	17	< 3

Dissolved Reactive Phosphorous (g/m3)	0.009	< 0.004	0.017	0.014	0.006	0.015	< 0.004	0.006	< 0.004	0.008	< 0.004	0.005
Total P (g/m3)	0.032	0.024	0.022	0.05	0.006	0.022	0.006	0.016	0.005	0.013	0.007	0.007
Total N (g/m3)	0.3	0.28	< 0.11	0.5	0.13	< 0.11	0.3	0.2	0.59	< 0.3	0.2	< 0.11
Total Kjeldahl N (g/m3)	0.3	0.28	< 0.10	0.5	0.13	< 0.10	0.3	0.2	0.58	< 0.2	< 0.2	< 0.10
Total Ammoniacal - N (g/m3)	0.023	0.063	< 0.010	0.12	< 0.010	< 0.010	< 0.010	0.031	< 0.010	0.021	< 0.010	< 0.010
Nitrate-N + Nitrite-N (g/m3)	0.002	< 0.002	< 0.010	0.014	< 0.002	0.003	0.007	0.024	0.002	< 0.002	0.016	< 0.002
Date	42769	42769	42769	42769	42769	42769	42768	42768	42768	42768	42768	42768
Time	8:40am	8:20am	7:50am	9:15am	10:05am	10:25am	12:50pm	12:15pm	11:45am	10:10am	9:40am	9:20am

Neap tide results

Round 1	Opito Bay Stream mouth	Kuaotunu Stream mouth	Whitianga Stream mouth	Tairua Stream mouth
	Site 1	Site 4	Site 7	Site 10
pH	6.86	7.5	7.67	7.37
DO (%)	95	94.5	99.7	106.2
Temperature (°C)	21.9	21.3	19.6	19.6
Salinity (psu)	23.88	14.78	26.49	33.95
E.coli (cfu/100mL)	32	500	80	1
Enterococci (cfu/100mL)	22	440	90	7
Total faecal coliforms (cfu/100mL)	41	600	80	28
TSS (g/m3)	6	9	7	8
Dissolved Reactive Phosphorous (g/m3)	0.004	0.004	0.008	0.006
Total P (g/m3)	0.007	0.014	0.016	0.01
Total N (g/m3)	0.3	0.3	0.2	0.3
Total Kjeldahl N (g/m3)	0.2	0.3	0.2	0.2
Total Ammoniacal - N (g/m3)	0.01	0.01	0.01	0.01
Nitrate-N + Nitrite-N (g/m3)	0.002	0.002	0.042	0.002
Date	20/01/2017	20/01/2017	19/01/2017	19/01/2017
Time	1:45pm	2:15pm	2:30pm	1:30pm

Round 2

	Site 1	Site 4	Site 7	Site 10
pH	8.04	7.93	7.89	7.75
DO (%)	102	104.1	109.4	127.5
Temperature (°C)	23.3	21.6	23.9	23.3
Salinity (psu)	31.87	32.12	33.8	33.84
E.coli (cfu/100mL)	120	60	3	3
Enterococci (cfu/100mL)	62	60	2	5
Total faecal coliforms (cfu/100mL)	150	90	3	3
TSS (g/m3)	5	6	50	41
Dissolved Reactive Phosphorous (g/m3)	< 0.004	0.013	0.01	0.007
Total P (g/m3)	0.008	0.019	0.028	0.011
Total N (g/m3)	< 0.3	0.2	< 0.3	< 0.3
Total Kjeldahl N (g/m3)	< 0.2	< 0.2	< 0.2	< 0.2
Total Ammoniacal - N (g/m3)	< 0.010	0.031	< 0.010	0.013
Nitrate-N + Nitrite-N (g/m3)	0.005	0.008	0.007	0.003
Date	7/03/2017	7/03/2017	6/03/2017	6/03/2017
Time	2:15pm	2:40pm	2:50pm	2:20pm

Spring tide results

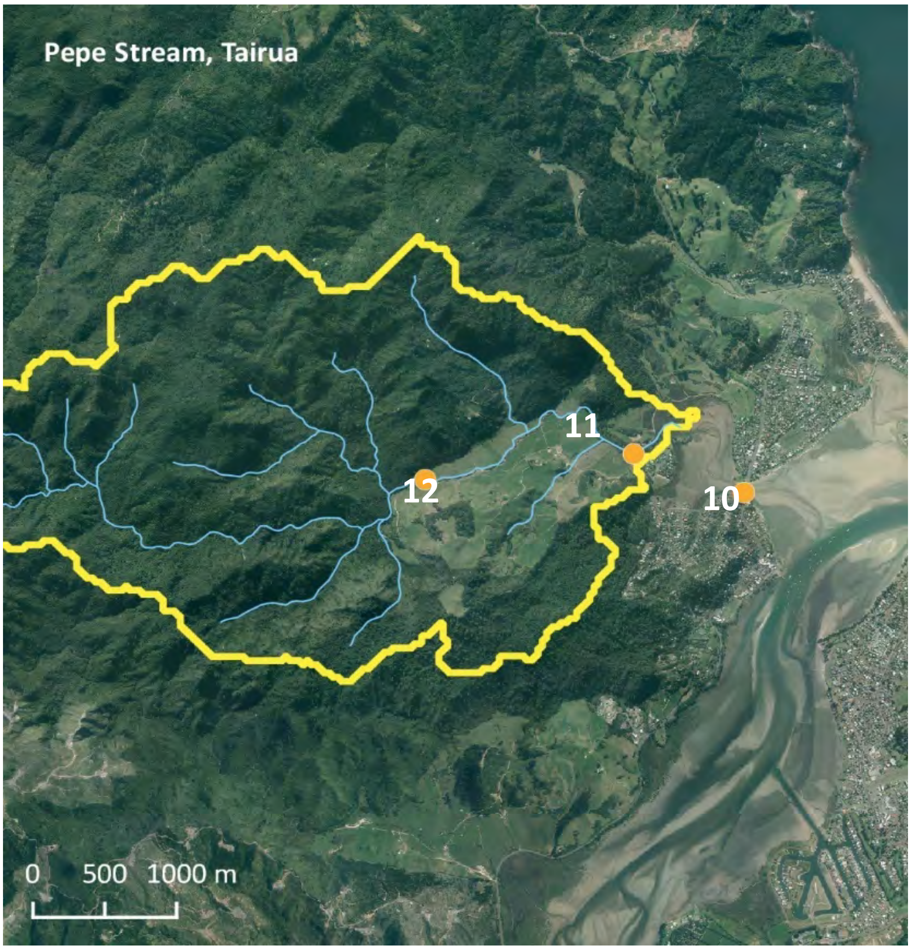
Round 1	Opito Bay Stream mouth	Kuaotunu Stream mouth	Whitianga Stream mouth	Tairua Stream mouth
	Site 1	Site 4	Site 7	Site 10
pH	6.94	7.61	7.49	7.84
DO (%)	114.1	99.2	101	95.9
Temperature (°C)	26.1	26.2	21.9	21.1
Salinity (psu)	24.69	30.62	30.08	32.65
E.coli (cfu/100mL)	620	250	520	6
Enterococci (cfu/100mL)	590	440	400	5
Total faecal coliforms (cfu/100mL)	680	290	640	6
TSS (g/m3)	13	23	37	30
Dissolved Reactive Phosphorous (g/m3)	< 0.004	< 0.004	0.011	0.005
Total P (g/m3)	0.018	0.022	0.024	0.009
Total N (g/m3)	0.3	< 0.3	< 0.3	0.2
Total Kjeldahl N (g/m3)	0.3	< 0.2	< 0.2	0.2
Total Ammoniacal - N (g/m3)	< 0.010	0.031	0.026	0.017
Nitrate-N + Nitrite-N (g/m3)	0.017	0.018	0.016	0.017
Date	27/02/2017	27/07/2017	28/02/2017	28/02/2017
Time	8:55pm	9:20pm	9:20am	10:10am

Round 2				
	Site 1	Site 4	Site 7	Site 10
pH	7.87	7.85	7.29	7.6
DO (%)	98.8	93.6	68.2	91.7
Temperature (°C)	19.8	20.1	19.7	19.3
Salinity (psu)	31.59	31.56	10.24	21.17
E.coli (cfu/100mL)	1000	1200	420	1600
Enterococci (cfu/100mL)	900	1200	390	130
Total faecal coliforms (cfu/100mL)	900	1400	70	900
TSS (g/m3)	8	6	14	9
Dissolved Reactive Phosphorous (g/m3)	0.004	0.025	0.004	0.016
Total P (g/m3)	0.01	< 0.004	0.013	0.042
Total N (g/m3)	0.4	0.3	< 0.3	< 0.3
Total Kjeldahl N (g/m3)	0.4	< 0.2	< 0.2	< 0.2
Total Ammoniacal - N (g/m3)	0.011	0.014	0.012	0.062
Nitrate-N + Nitrite-N (g/m3)	0.02	0.09	0.025	0.101
Date	31/03/2017	31/03/2017	30/03/2017	30/03/2017
Time	10:45AM	11:20AM	10:10AM	11:20AM

Appendix 4 – Site location maps and current resource consent maps

Pepe Stream, Tairua

The Pepe Stream catchment is located in Tairua. The three sampling locations for the Pepe Stream catchment are shown in below, and coordinates for the sample site locations are shown in the table below.



Pepe Stream Catchment and Sampling Locations 10-12, Tairua.

Pepe Stream Catchment Sample Site Coordinates

Site Name	Easting	Northing
Site 10 - Pepe mouth	1853435	5900906
Site 11 - Pepe mid	1852667	5901185
Site 12 - Pepe upper	1851215	5901000

Site 10: Pepe mouth
Site access is via the Pepe Stream Bridge. This site will capture contaminant contributions from urban sources.

Site 11: Pepe mid
Site access is through farmland near 15 Laycock Road. This site will capture contaminant contributions from pastoral sources.

Site 12: Pepe upper

Site access is through farmland near 55 Laycock Road Buffalo Beach Road. This site will capture contaminant contributions from the native/exotic forest land cover.

Taputaputea Stream, Whitianga

The Taputaputea catchment is located in Whitianga. The three sampling locations for the Taputaputea catchment are shown below, and coordinates for the sample site locations are shown in the table below.

Taputaputea Stream Catchment and Sampling Locations 7-9, Whitianga

Taputaputea Stream Catchment Sample Site Coordinates

Site Name	Easting	Northing
Site 7- Taputapuatea mouth	1840776	5922054
Site 8 - Taputapuatea mid	1840523	5922597
Site 9 - Taputapuatea upper	1838591	5922263

Site 7: Taputaputea mouth

Site access is via Buffalo Beach Road. This site will capture contaminant contributions from urban sources.

Site 8: Taputaputea mid

Site access is via a public walkway off River Crescent. This site will capture contaminant contributions from pastoral sources.

Site 9: Taputaputea upper

Site access is via a public gravel road near 152 Moewai Road. This site will capture contaminant contributions from the native/exotic forest land cover.

Kuaototunu Stream, Kuaotunu

The Kuaotunu Stream catchment is located in Kuaotunu. The three sampling locations for the Kuaotunu Stream catchment are shown below, and coordinates for the sample site locations are shown in the table below.

Kuaotunu Stream Catchment and Sampling Locations 4-6, Kuaotunu

Kuaotunu Stream Catchment Sample Site Coordinates

Site Name	Easting	Northing
Site 4 - Kuaotunu mouth	1843786	5932500
Site 5 - Kuaotunu mid	1843697	5931371
Site 6 - Kuaotunu upper	1843388	5930599

Site 4: Kuaotunu mouth
Site access is via a walk bridge opposite Luke’s Kitchen. This site will capture contaminant contributions from urban sources.

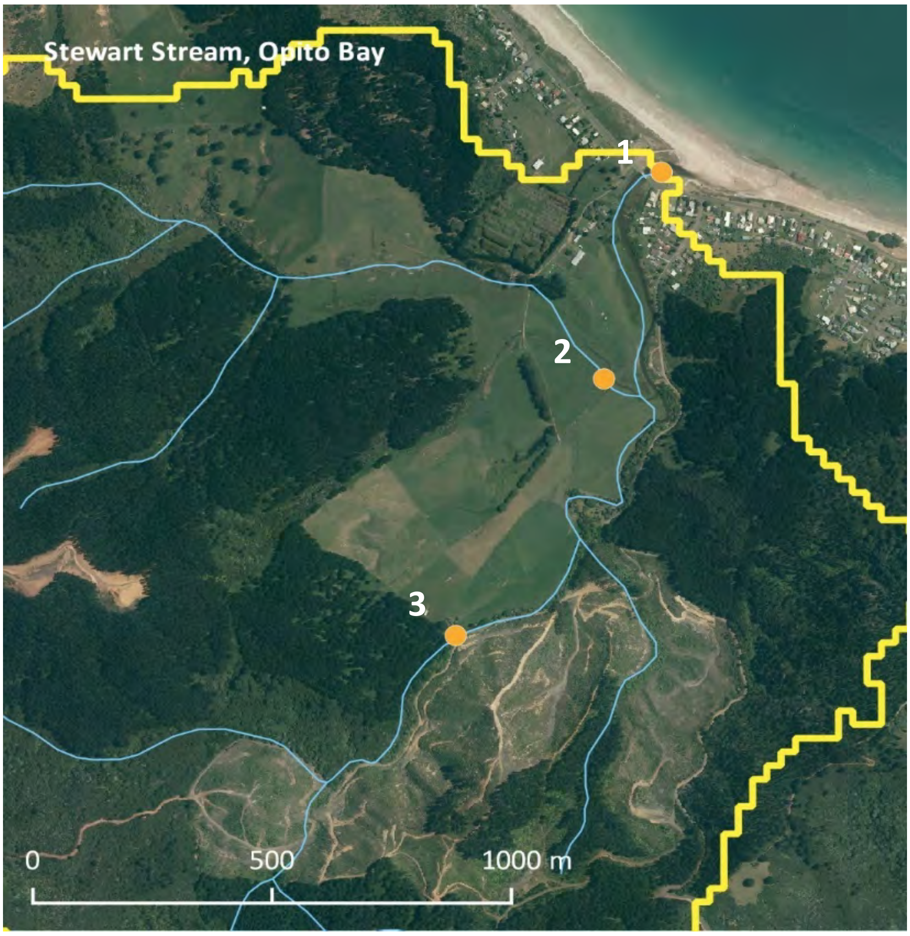
Site 5: Kuaotunu mid
Site access is via Kuaotunu Wharekaho Rd or Waitaia Rd. This site will capture contaminant contributions from pastoral sources.

Site 6: Kuaotunu upper

Site access is via Kuaotunu Wharekaho Rd. This site will capture contaminant contributions from the native/exotic forest land cover.

Stewart Stream, Opito Bay

The Stewart Stream catchment is located in Opito Bay. The three sampling locations for the Stewart Stream catchment are shown below, and coordinates for the sample site locations are shown in the table below.



Stewart Stream Catchment Map and Sampling Locations 1-3, Opito Bay

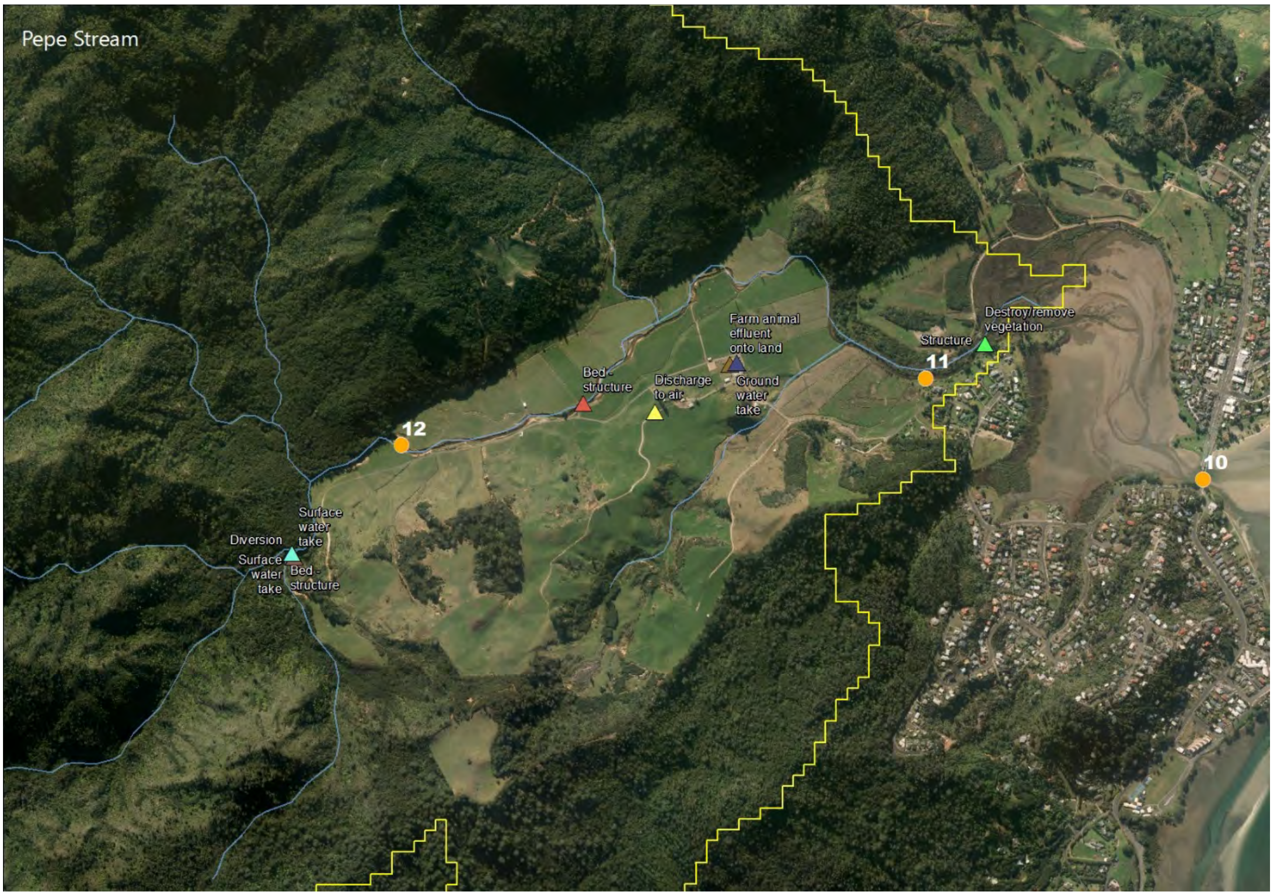
Stewart Stream Catchment Sample Site Coordinates

Site Name	Easting	Northing
Site 1 - Stewart mouth	1850183	5932481
Site 2 - Stewart mid	1850063	5932026
Site 3 - Stewart upper	1849753	5931461

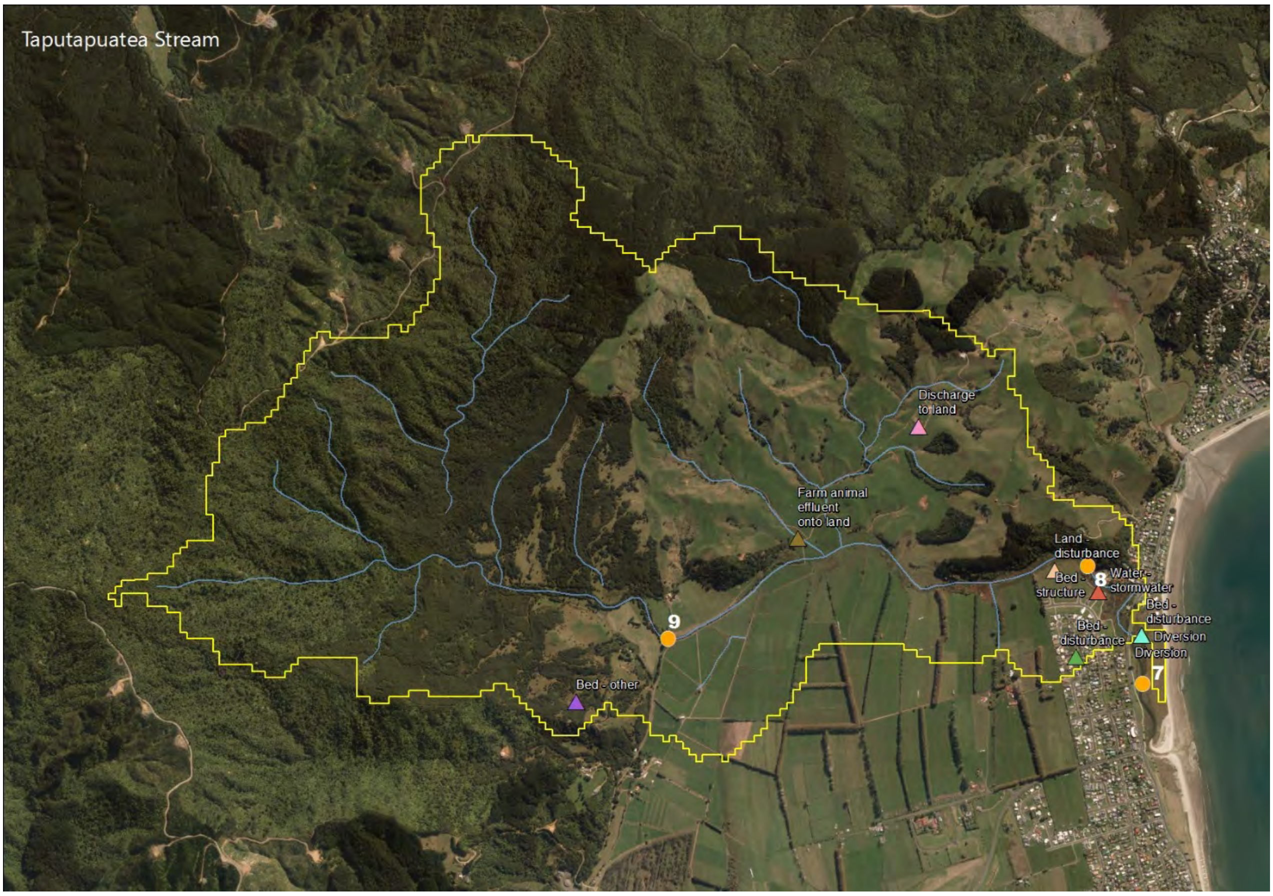
Site 1: Stewart mouth
Site access is via a platform by Stewart Stream Bridge. This site will capture contaminant contributions from urban sources.

Site 2: Stewart mid
Site access is across farmland located at 958 Black Jack Rd. This site will capture contaminant contributions from pastoral sources.

Site 3: Stewart upper
Site access is via Matapaua Bay Rd or through farmland at 958 Black Jack Road. This site will capture contaminant contributions from the native/exotic forest land cover.



Pepe Stream catchment including locations of current resource consents



Taputapuatea Stream catchment including locations of current resource consents

Kuaotunu Stream catchment including locations of current resource consents

Stewart Stream catchment including locations of current resource consent

Appendix 5 – Statistical analyses

A5.1: Results from two-tailed t-tests comparing mean E. coli levels in each stream during wet weather and dry weather sampling events. Data from all sampling locations has been combined for each stream.

Stream	t	*df*	p
Kuaotunu	-3.617	10	0.005
Stewart	-5.323	10	<0.001
Tuputapuatea	-4.888	10	<0.001
Pepe	-4.006	10	0.002

A5.2: Results from One-way ANOVA tests comparing mean E. coli levels between each sampled stream during dry weather and wet weather sampling events. Data from all sampling locations has been combined for each stream.

Sampling event	SS	MS	*df*	F	p
Dry weather	2.736	0.912	3, 20	0.488	0.694
Wet weather	0.617	0.206	3, 20	0.192	0.901

A5.3: Results from two-tailed t-tests comparing mean E. coli levels at each sampling location during wet weather and dry weather sampling events. Data from all four streams has been combined for each sampling location.

Sample location	t	df	p
Bush	-7.732	14	<0.001
Pasture	-5.231	14	<0.001
Stream Mouth	-5.496	14	<0.001

A5.4: Results from One-way ANOVA and Holm-Sidak post-hoc tests comparing mean *E. coli* levels between each sampling location during dry weather and wet weather sampling events. Data from all four streams has been combined for each sampling location.

Analysis	SS	MS	*df*	F	p
Streams	7.112	2.371	3, 63	0.445	0.722

A5.5: Results from One-way ANOVA test comparing mean *E. coli* levels between each stream. Data all sampling events and locations has been combined for each stream.

Sampling event	SS	MS	*df*	F	p
Dry weather	15.042	7.521	2, 23	6.304	0.007
Wet weather	2.22	1.11	2, 23	1.175	0.328
Post-hoc comparisons	t	p			
Bush vs Pasture	3.058	0.012			
Pasture vs Stream mouth	3.092	0.016			
Bush vs Stream mouth	0.0339	0.973			

Appendix 6 – Stream gauging and contaminant load calculations

Wet weather contaminant loads

E.coli loads

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Average Concentration (cfu/100mL)	5,550	6,300	2,400	9,900	2,350	2,200	10,790	8,900	11,650	5,700	15,000	3,800
Average Flow (m3/s)	No flow	0.17	0.13	1.29	0.59	1.01	0.08	0.17	0.09	No flow	0.78	0.48
Contaminant Load (cfu/m3/s)	NA	10,563,380	3,059,929	127,769,989	13,820,027	22,244,560	8,429,688	14,979,905	10,558,989	NA	117,595,522	18,181,536

Dry weather contaminant loads

E.coli loads

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Average Concentration (cfu/100mL)	600	620	97.5	565	1900	115	114	415	83.5	25.5	1250	350
Average Flow (m3/s)	0.68	0.13	0.03	No flow	0.02	0.04	1.08	0.57	0.02	2.99	0.89	0.09
Contaminant Load (cfu/m3/s)	4,099,558	805,647	33,993	NA	438,051	45,249	1,230,912	2,380,880	16,449	763,399	11,116,793	317,167

Appendix 7 – FST laboratory reports

Ruminant PCR marker reports

ESR No	Site	Sample Number	Date	Event	General GenBac / 100 mls	Rumt BacR / 100 mls	Proportion Ruminant	Ruminant Sheep / 100 mls	Ruminant Cow / 100 mls	Conclusion / Comment
CMB170578	1	1718843.6	3/02/2017	Dry	76000	440	1 - 10%			The highest levels GenBac associated with the first dry event where ruminant and avian markers detected with ruminant at higher levels. The Wet samples despite having up to a 10 fold increase in E. coli and enterococci over the spring samples, did not have a concurrent increase in GenBac or the other DNA markers. This was a trend in many of the other samples. The two wet samples had ruminant pollution but at levels not consistent with fresh inputs. BacH was detected at low levels in 3 samples, but require detection of both human markers to confirm human source
CMB170585	1	1721246.1	9/02/2017	Wet	5300	120	10 - 50%			
CMB170591	1	1731689.1	27/02/2017	Spring	3100	ND	ND			
CMB170594	1	1747726.1	27/03/2017	Wet	2200	73	10 - 50%			
CMB170607	1	1751219.1	31/03/2017	Spring	4000	ND	ND			
CMB170572	2	1706582.5	11/01/2017	Dry	6400	99	10 - 50%			Dry samples consistent with ruminant source with low levels of avian contributions. Wet samples despite significant increase in E. coli and enterococci actually had decrease in DNA markers suggesting the increase in E. coli and enterococci not associated with faecal source. Ruminant source in one of the wet samples with the other having such low levels that no marker was positive.
CMB170577	2	1718843.5	3/02/2017	Dry	17000	330	10 - 50%			
CMB170586	2	1721246.2	9/02/2017	Wet	2200	110	10 - 50%			
CMB170595	2	1747726.2	27/03/2017	Wet	87	ND	ND			
CMB170576	3	1718843.4	3/02/2017	Dry	3300	ND	ND			The PCR marker results are not consistent with the high levels of E. coli being from a fresh faecal source. No faecal source identified
CMB170587	3	1721246.3	9/02/2017	Wet	2700	ND	ND			
CMB170596	3	1747726.3	27/03/2017	Wet	360	ND	ND			

ESR No	Site	Sample Number	Date	Event	General GenBac / 100 mls	Rumt BacR / 100 mls	Proportion Ruminant	Ruminant Sheep / 100 mls	Ruminant Cow / 100 mls	Conclusion / Comment
CMB170571	4	1706582.3	11/01/2017	Dry	91000	650	1 - 10%			High levels of GenBac in all samples with ruminant and possum sources identified. Neap sample has both human markers suggesting a possible human source, but the other BacH detection likely cross reaction with possum faeces. Ruminant source mix of sheep and cow.
CMB170573	4	1711657.2	20/01/2017	Neap	92000	2900	10 - 50%	ND	ND	
CMB170588	4	1721246.4	9/02/2017	Wet	190000	11000	10 - 50%	150	detected, <LOQ	
CMB170592	4	1731689.2	27/02/2017	Spring	44000	1300	10 - 50%	ND	ND	
CMB170597	4	1747726.4	27/03/2017	Wet	32000	2200	50 - 100%	ND	detected, <LOQ	
CMB170608	4	1751219.2	31/03/2017	Spring	50000	1400	10 - 50%	57	ND	
CMB170570	5	1706582.2	11/01/2017	Dry	45000	ND	ND			Elevated GenBac and possum marker in all samples with avian in first 3 samples and ruminant in the second wet sample
CMB170575	5	1718843.2	3/02/2017	Dry	150000	ND	ND			
CMB170589	5	1721246.5	9/02/2017	Wet	78000	ND	ND			
CMB170598	5	1747726.5	27/03/2017	Wet	11000	310	10 - 50%			
CMB170569	6	1706582.1	11/01/2017	Dry	28000	380	1 - 10%			Inverse relationship between E. coli/enterococci and GenBac suggesting not a typical fresh faecal source. Ruminant in all samples, avian in dry sample and in wet samples appearance of possum marker which suggests BacH is cross reaction.
CMB170590	6	1721246.6	9/02/2017	Wet	17000	360	10 - 50%			
CMB170599	6	1747726.6	27/03/2017	Wet	4100	190	10 - 50%			

ESR No	Site	Sample Number	Date	Event	General GenBac / 100 mls	Rumt BacR / 100 mls	Proportion Ruminant	Ruminant Sheep / 100 mls	Ruminant Cow / 100 mls	Conclusion / Comment
CMB170584	7	1721244.6	9/02/2017	Wet	19000	ND	ND			Elevated GenBac with highest levels in second spring sample. First wet sample has a strong BacH signal, but not second human marker or possum suggesting cat, dog, rabbit, goat or chicken as possible source. Other three samples ruminant marker with possum also in 30/3 spring sample. Possible human in 28/2 spring sample although also ruminant and avian sources in this sample. Ruminant source not identified
CMB170593	7	1731689.3	28/02/2017	Spring	24000	84	1 - 10%			
CMB170605	7	1747734.6	27/03/2017	Wet	10000	1500	50 - 100%	ND	ND	
CMB170606	7	1750420.2	30/03/2017	Spring	110000	1800	10 - 50%	ND	ND	
CMB170568	8	1706508.5	10/01/2017	Dry	110000	250	1 - 10%			Very high E. coli and enterococci in wet samples with equal or lower GenBac. Ruminant in all samples and in first two samples both possum and avian marker. Possum marker supports BacH detection as cross reaction with possum. Second wet sample ruminant. Ruminant source in first wet sample - cow
CMB170583	8	1721244.5	9/02/2017	Wet	110000	3400	10 - 50%	ND	detected, <LOQ	
CMB170604	8	1747734.5	27/03/2017	Wet	5200	260	10 - 50%			
CMB170582	9	1721244.4	9/02/2017	Wet	20000	740	10 - 50%	ND	ND	Faecal contamination - ruminant dominated, but also possum and avian sources. Ruminant source not identified.
CMB170603	9	1747734.4	27/03/2017	Wet	8000	180	10 - 50%			
CMB170581	10	1721244.3	9/02/2017	Wet	26000	340	1 - 10%			Faecal contamination - ruminant dominated, but also possum and avian sources
CMB170602	10	1747734.3	27/03/2017	Wet	3100	230	50 - 100%			
CMB170574	11	1718520.2	2/02/2017	Dry	99000	detected, <LOQ	NC			In dry conditions avian, low level possum. Wet weather ruminant (cow) dominated with also possum and avian in first wet sample
CMB170580	11	1721244.2	9/02/2017	Wet	160000	8600	10 - 50%	ND	77	
CMB170601	11	1747734.2	27/03/2017	Wet	7000	720	50 - 100%	ND	ND	

Human, possum, ruminant, and avian PCR marker reports

ESR No	Site	Sample Number	Date	Event	General GenBac	Human BacH	Human BiADO	Possum Bac	Rumt BacR	Proportion Ruminant	Avian GFD	Conclusion / Comment
CMB170578	1	1718843.6	3/02/2017	Dry	76000	detected, <LOQ	ND	ND	440	1 - 10%	89	The highest levels GenBac associated with the first dry event where ruminant and avian markers detected with ruminant at higher levels. The Wet samples despite having up to a 10 fold increase in E. coli and enterococci over the spring samples, did not have a concurrent increase in GenBac or the other DNA markers. This was a trend in many of the other samples. The two wet samples had ruminant pollution but at levels not consistent with fresh inputs. BacH was detected at low levels in 3 samples, but require detection of both human markers to confirm human source
CMB170585	1	1721246.1	9/02/2017	Wet	5300	detected, <LOQ	ND	ND	120	10 - 50%	ND	
CMB170591	1	1731689.1	27/02/2017	Spring	3100	ND	ND	ND	ND	ND	ND	
CMB170594	1	1747726.1	27/03/2017	Wet	2200	ND	ND	ND	73	10 - 50%	ND	
CMB170607	1	1751219.1	31/03/2017	Spring	4000	detected, <LOQ	ND	ND	ND	ND	ND	
CMB170572	2	1706582.5	11/01/2017	Dry	6400	detected, <LOQ	ND	ND	99	10 - 50%	detected, <LOQ	Dry samples consistent with ruminant source with low levels of avian contributions. Wet samples despite significant increase in E. coli and enterococci actually had decrease in DNA markers suggesting the increase in E. coli and enterococci not associated with faecal source. Ruminant source in one of the wet samples with the other having such low levels that no marker was positive.
CMB170577	2	1718843.5	3/02/2017	Dry	17000	ND	ND	ND	330	10 - 50%	detected, <LOQ	
CMB170586	2	1721246.2	9/02/2017	Wet	2200	detected, <LOQ	ND	ND	110	10 - 50%	ND	
CMB170595	2	1747726.2	27/03/2017	Wet	87	ND	ND	ND	ND	ND	ND	
CMB170576	3	1718843.4	3/02/2017	Dry	3300	detected, <LOQ	ND	ND	ND	ND	ND	The PCR marker results are not consistent with the high levels of E. coli being from a fresh faecal source. No faecal source identified
CMB170587	3	1721246.3	9/02/2017	Wet	2700	44	ND	ND	ND	ND	ND	
CMB170596	3	1747726.3	27/03/2017	Wet	360	ND	ND	ND	ND	ND	ND	

ESR No	Site	Sample Number	Date	Event	General GenBac	Human BacH	Human BiADO	Possum Bac	Rumt BacR	Proportion Ruminant	Avian GFD	Conclusion / Comment
CMB170571	4	1706582.3	11/01/2017	Dry	91000	57	ND	present	650	1 - 10%	180	High levels of GenBac in all samples with ruminant and possum sources identified. Neap sample has both human markers suggesting a possible human source, but the other BacH detection likely cross reaction with possum faeces
CMB170573	4	1711657.2	20/01/2017	Neap	92000	280	detected, <LOQ	present	2900	10 - 50%	110	
CMB170588	4	1721246.4	9/02/2017	Wet	190000	290	ND	present	11000	10 - 50%	360	
CMB170592	4	1731689.2	27/02/2017	Spring	44000	detected, <LOQ	ND	ND	1300	10 - 50%	detected, <LOQ	
CMB170597	4	1747726.4	27/03/2017	Wet	32000	detected, <LOQ	ND	present	2200	50 - 100%	ND	
CMB170608	4	1751219.2	31/03/2017	Spring	50000	78	ND	present	1400	10 - 50%	92	
CMB170570	5	1706582.2	11/01/2017	Dry	45000	77	ND	present	ND	ND	detected, <LOQ	Elevated GenBac and possum marker in all samples with avian in first 3 samples and ruminant in the second wet sample
CMB170575	5	1718843.2	3/02/2017	Dry	150000	210	ND	present	ND	ND	570	
CMB170589	5	1721246.5	9/02/2017	Wet	78000	310	ND	present	ND	ND	150	
CMB170598	5	1747726.5	27/03/2017	Wet	11000	49	ND	present	310	10 - 50%	ND	
CMB170569	6	1706582.1	11/01/2017	Dry	28000	ND	ND	ND	380	1 - 10%	110	Inverse relationship between E. coli/enterococci and GenBac suggesting not a typical fresh faecal source. Ruminant in all samples, avian in dry sample and in wet samples appearance of possum marker which suggests BacH is cross reaction.
CMB170590	6	1721246.6	9/02/2017	Wet	17000	170	ND	present	360	10 - 50%	detected, <LOQ	
CMB170599	6	1747726.6	27/03/2017	Wet	4100	75	ND	present	190	10 - 50%	ND	

ESR No	Site	Sample Number	Date	Event	General GenBac	Human BacH	Human BiADO	Possum Bac	Rumt BacR	Proportion Ruminant	Avian GFD	Conclusion / Comment
CMB170584	7	1721244.6	9/02/2017	Wet	19000	2200	ND	ND	ND	ND	detected, <LOQ	Elevated GenBac with highest levels in second spring sample. First wet sample has a strong BacH signal, but not second human marker or possum suggesting cat, dog, rabbit, goat or chicken as possible source. Other three samples ruminant marker with possum also in 30/3 spring sample. Possible human in 28/2 spring sample although also ruminant and avian sources in this sample.
CMB170593	7	1731689.3	28/02/2017	Spring	24000	150	detected, <LOQ	ND	84	1 - 10%	160	
CMB170605	7	1747734.6	27/03/2017	Wet	10000	detected, <LOQ	ND	ND	1500	50 - 100%	ND	
CMB170606	7	1750420.2	30/03/2017	Spring	110000	60	ND	present	1800	10 - 50%	ND	
CMB170568	8	1706508.5	10/01/2017	Dry	110000	92	ND	present	250	1 - 10%	200	Very high E. coli and enterococci in wet samples with equal or lower GenBac. Ruminant in all samples and in first two samples both possum and avian marker. Possum marker supports BacH detection as cross reaction with possum. Second wet sample ruminant
CMB170583	8	1721244.5	9/02/2017	Wet	110000	380	ND	present	3400	10 - 50%	260	
CMB170604	8	1747734.5	27/03/2017	Wet	5200	detected, <LOQ	ND	ND	260	10 - 50%	ND	
CMB170582	9	1721244.4	9/02/2017	Wet	20000	61	ND	present	740	10 - 50%	120	Faecal contamination - ruminant dominated, but also possum and avian sources
CMB170603	9	1747734.4	27/03/2017	Wet	8000	140	ND	present	180	10 - 50%	ND	
CMB170581	10	1721244.3	9/02/2017	Wet	26000	detected, <LOQ	ND	present	340	1 - 10%	110	Faecal contamination - ruminant dominated, but also possum and avian sources
CMB170602	10	1747734.3	27/03/2017	Wet	3100	ND	ND	present	230	50 - 100%	ND	
CMB170574	11	1718520.2	2/02/2017	Dry	99000	detected, <LOQ	ND	ND	detected, <LOQ	NC	350	In dry conditions avian, low level possum. Wet weather ruminant dominated with also possum and avian in first wet sample
CMB170580	11	1721244.2	9/02/2017	Wet	160000	240	ND	present	8600	10 - 50%	280	
CMB170601	11	1747734.2	27/03/2017	Wet	7000	detected, <LOQ	ND	present	720	50 - 100%	ND	

ESR No	Site	Sample Number	Date	Event	General GenBac	Human BacH	Human BiADO	Possum Bac	Rumt BacR	Proportion Ruminant	Avian GFD	Conclusion / Comment
CMB170579	12	1721244.1	9/02/2017	Wet	13000	61	ND	present	ND	ND	ND	Possum source in both samples
CMB170600	12	1747734.1	27/03/2017	Wet	1000	detected, <LOQ	ND	present	ND	ND	ND	

Abbreviations: NA = sample was not analysed for this marker.
Detected, <LOQ = the marker was detected but at a level less than the limit of quantitation (LOQ)
ND = not detected, sample was analysed, but the marker was not detected.
NC = not calculated, sample contained a low level of ruminant marker and at this low level a ratio calculation is not valid