Auckland West Coast Lagoons: Sources of Faecal Contamination

April 2016 Technical Report 2016/012

Auckland Council
Technical Report 2016/012
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-0-9941367-6-3 (Print)
ISBN 978-0-9941367-7-0 (PDF)

This report has been peer reviewed by the Peer Review Panel.

Review completed on 14 April 2016
Reviewed by two reviewers

Approved for Auckland Council publication by:

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Position: Manager, Research and Evaluation Unit (RIMU)

Date: 14 April 2016

Recommended citation

Noble, A and Neale, M W (2016). Auckland west coast lagoons: sources of faecal contamination. Auckland Council technical report, TR2016/012

Auckland West Coast Lagoons: Sources of Faecal Contamination

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Executive summary

The west coast beaches at Karekare, Piha, North Piha and Te Henga (Bethells) have excellent water quality based on long-term monitoring information; however, the lagoons at these locations have poor water quality. The lagoons have a history of high faecal indicator bacteria (*Escherichia coli*) concentrations, since at least 1985. This long-term contamination has remained consistently high since Auckland Council monitoring began in summer 2003–2004 consistent with the Ministry for the Environment's 2003 guidelines, *Microbiological water quality guidelines for marine and freshwater recreational areas*. Previous investigations have used microbial source tracking (MST) analysis of water samples from the lagoons to indicate the biological sources of this contamination. This testing revealed a complex mix of sources from a range of animals, including dogs, birds, ruminants and humans.

The lagoons are often unsuitable for swimming

Water quality monitoring has shown that the lagoons are frequently unsuitable for recreational activities and during the peak summer holiday season, Auckland Council is often required to place signs advising people not to swim in the lagoons, on occasions for up to two weeks. In order to effectively manage the contamination, it is important to know where in the catchment the source is and from what animal sources any faecal contamination is originating. Therefore, the purpose of this investigation is to develop a more complete understanding of the biological and geographical sources of the microbiological contamination observed through the Safeswim monitoring programme.

Multiple faecal sources identified, but some could not be identified

The investigation has confirmed the presence of a complex mix of microbiological contamination in the west coast lagoons. All of the lagoons had high concentrations of *E. coli* at times during the 2013-2014 summer and all 49 samples subject to MST analysis tested positive for the general faecal marker, which is a more reliable indicator of faecal contamination. A range of animal faecal sources were contaminating the west coast lagoons and their tributaries, including human, dogs, birds and ruminants, however all of the lagoons had occasions where the faecal source could not be detected.

The Piha Lagoon was the most chronically contaminated, having the highest concentration of *E. coli* of any of the study lagoons. The Piha stormwater inlet that was sampled had high concentrations of *E. coli* and tested positive for human markers, indicating that this discharge is one source of human faecal contamination to the lagoon. Human faecal contamination was consistently detected in the lagoon and further up Piha Stream, with 43 per cent of the MST samples from this catchment having evidence of human contamination, although in addition bird and dog markers were consistently detected in the lower parts of the catchment.

The samples from the Karekare Lagoon catchment had moderate concentrations of *E. coli*, but despite the detection of the general faecal marker in all five MST samples, a reliable source could be detected in only one of these. A human marker was detected in a single sample from the Company Stream, which is potentially a consequence of a large rain event overwhelming on-site wastewater systems.

The North Piha catchment sample sites had moderate levels of *E. coli*, but this was accompanied by strong evidence of human contamination at the Marawhara Lagoon site as five (of six) MST samples tested positive for human markers. The geographic source of this contamination was unclear and it is likely that there is a currently unknown contribution of wastewater to the lagoon requiring further investigation.

The results from the Te Henga Lagoon catchment provided very strong evidence of faecal contamination by ruminant animals, suggesting that improved livestock management could reduce the level of contamination in this catchment. However, bird and dog sources were also common in this catchment.

Managing contamination sources should help to minimise the faecal contamination

The report provides a number of recommendations aimed at reducing the level of faecal contamination in the lagoons. They include fencing riparian areas to exclude stock, investigations of and improved management of on-site wastewater systems, practical steps to manage faecal contamination from dogs and birds, and installing permanent warning signs about the public health risk of swimming in the lagoons.

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1.0 Introduction

The west coast beaches and lagoons at Karekare, Piha, North Piha and Te Henga (Bethells) are special places. The beaches there have very good water quality. However, recreational water quality monitoring for faecal indicator bacteria *Escherichia coli (E. coli)* concentrations over the past decade has shown that the freshwater lagoons behind these beaches have chronic microbiological water quality problems. This contamination has been recognised for over 30 years (Challis, 1985).

The lagoons have a chronic microbiological water quality problem

The microbiological water quality of the west coast lagoons has been monitored during summer under the council bathing beach ‘Safeswim’ programme in accordance with the Ministry for the Environment (MfE) national guidelines for recreational areas (MfE, 2003) since summer 2003–2004. The Safeswim monitoring programme (see Appendix A for more details) is designed to provide regular assessments of water quality at a range of locations in the region that are used for recreation (including marine and freshwater beaches). Under the programme, the council monitors 71 (2015-2016 season) beaches in the Auckland region on a weekly basis and the results are communicated to the public via the Safeswim webpage. Consistent with the MfE guideline the council takes action to warn the public of health risks if the results of testing indicate elevated levels of *E. coli*, including erecting warning signs on the affected beach.

Data generated through the Safeswim monitoring programme shows the lagoons have chronic microbiological water quality problems and this contamination has been associated with human and animal (domestic and feral) sources of faecal matter (Noble, 2014). The Safeswim monitoring results show that according to the MfE national guidelines and the National Policy Statement for Freshwater Management (Human Health for recreation attribute table (MfE, 2014)), the lagoons frequently pose a health risk, which makes them unsuitable for recreational uses.

We need to know what faecal sources are causing the contamination

Auckland Council’s Environmental Services Unit (ESU) has recently published an Environmental Services Operational Strategy (ESOS) 2015–2018. One of the priority environmental outcomes stated in the ESOS is ‘healthy waterways and harbours’. This outcome supports the need to improve water quality of the west coast lagoons.

Monitoring results from the Safeswim programme have identified chronic microbiological water quality contamination of the lagoons, but the limitations of *E. coli* monitoring mean it is difficult to develop an appropriate management response. First, the presence of *E. coli* does not necessarily confirm the presence of faecal contamination as they may survive, reproduce and establish self-sustaining populations in numerous aquatic and semi-aquatic environments (Walker *et al.,* 2015). Second, *E. coli* are ubiquitous in the intestines of warm-blooded animals, therefore the presence of faecally-derived *E. coli* may be from a range of possible animal hosts that makes effective management of any contamination difficult.

Recent advances in molecular techniques have led to the development of a microbial source tracking (MST) tools based on ribosomal DNA markers associated with the Bacteroidales order of bacteria (Bernhard and Field 2000, Roslev and Bukh, 2011). General and host-specific markers potentially allow the identification of whether high *E. coli* concentrations are a result of faecally-derived contamination and furthermore, what the source animal is. The benefits of knowing the source of faecal contamination allows a financially-efficient, targeted management response (Gilpin *et al*. 2002). Therefore, the aim of this investigation was to provide a spatial and temporal snap-shot of the faecal sources contaminating the west coast lagoons.

2.0 Methodology

Water samples were collected for *E. coli* testing and microbial source tracking (MST) in each of the four lagoons and at a number of sites upstream of each lagoon in attempt to identify the geographical source of any identified contamination. The sampling rationale and site descriptions are detailed in this section.

2.1 Sampling site description and rationale

A total of 15 sampling sites were sampled as part of this investigation. Four of the sites in the lagoons were existing Safeswim sampling locations (2013-2014 season) and an additional 11 upstream sites in these catchments. The additional sites were selected to provide greater spatial coverage of the contributing catchments of each lagoon for the tracking of potential faecal sources. The upstream sites were located to identify if different sub-catchments or tributaries were a source of microbiological contamination. The name, description and grid reference for each site is shown in Table 1. An overview map of the location of each site is shown in Figure 2, with more detailed location maps provided in Appendix B.

2.2 Water sampling

Water samples were collected in sterile 100mL bottles by Aqualab NZ Ltd laboratory staff. Samples were collected in knee deep water in the lagoons (0.5m) according to MfE guidelines (MfE, 2003). All other upstream *E. coli* samples were taken immediately below the surface.

Samples were chilled following collection and returned to the laboratory for immediate analysis. The samples were analysed using the Colilert test (APHA, 2012) which provides a Most Probable Number (MPN) of *E. coli* per 100mL (detection limit 10 *E. coli*/100mL) in accordance with the 2003 MfE national guidelines.

Two-litre water samples were collected for MST analysis at the same time and location as each sample collected for *E. coli* testing. Samples were stored in a chilly-bin with ice-packs, brought back to the laboratory, chilled and processed within 24 hours of sample collection (see next section).

2.3 Sampling frequency

The sampling programme utilised the field procedures and arrangements of the Safeswim programme to collect water samples. All sites in this investigation were therefore sampled weekly between 16 December 2013 and 11 March 2014 by Aqualab NZ Ltd staff under contract to Auckland Council. It should be noted that the Safeswim sampling programme ran between 4 November 2013 and 28 March 2014.

As described in Appendix A, the Safeswim programme retests any site where a single test result exceeds 260 *E. coli*/100mL (amber or red alert mode). Therefore the four Safeswim sites in this investigation were re-sampled when this threshold was met. However, for logistical reasons, the additional non-Safeswim sites in this investigation were only re-sampled if the test result from the Safeswim site in the same lagoon exceeded 550 *E. coli*/100mL (red alert mode).

Table 1: Sampling locations, rationale and descriptions.

Site name (number)	Site descriptions and rationale	Easting	Northing
Karekare			
Karekare Lagoon (443100)	Safeswim sampling location.	1731426	5905587
Karekare Stream (443102)	Ten metres upstream from the confluence with Company Stream. Chosen to determine if this tributary is contributing contamination to the lagoon.	1731599	5905632
Company Stream (443200)	Ten metres downstream of Kauri Rd bridge. Chosen to determine if this tributary is contributing contamination to the lagoon.	1731666	5905582
Piha			
Piha Lagoon (444005)	Safeswim sampling location.	1730899	5909265
Piha Stream (Domain) (444001)	Site located in-between the Piha Domain Tennis and Bowling Clubs. Chosen to determine how contamination varies along the Piha Stream.	1731049	5909077
Piha Stormwater (444002)	Sampled from the stormwater culvert inlet passing under Beach Valley Rd and discharging to the Piha Stream. Chosen to determine if stormwater discharging from the Seaview Rd sub-catchment into Piha Stream is a source of contamination.	1731213	5909049
Piha Stream (Seaview Rd Bridge) (444003)	Ten metres upstream of the Seaview Rd bridge Chosen to determine how contamination varies along the Piha Stream.	1731278	5909175
Piha Stream (Lookout Track) (444004)	Chosen to determine how contamination varies along the Piha Stream. Site accessed via Maungaroa ‘Lookout Track’ on Glenesk Rd.	1731821	5909415
North Piha			
Marawhara Lagoon (444500)	Safeswim sampling location.	1730561	5910117
Marawhara Stream (444501)	Marawhara Stream at Marine Parade bridge. Chosen to determine if this tributary of the lagoon is contributing contamination to the lagoon.	1730584	5910447
Whekatahi Lagoon (444400)	Whekatahi Creek opposite 147 Marine Parade North. Chosen to determine if this tributary is contaminated with faecal bacteria.	1730633	5909972
Te Henga			
Te Henga Lagoon (446000)	Safeswim sampling location.	1728739	5916238
Te Henga Surf Club (446001)	Waitakere River approximately 50m upstream of the Surf Club. Chosen to determine how contamination varies along the Waitakere River.	1729057	5916415
Weiti Creek (446002)	Weiti Creek at Bethells Rd bridge. Chosen to determine if this tributary is contributing contamination to the lagoon.	1729365	5917062
Waitakere River (446100)	Waitakere River approximately 10m above confluence with Weiti Stream. Chosen to determine if this tributary is contributing contamination to the lagoon	1729161	5917095

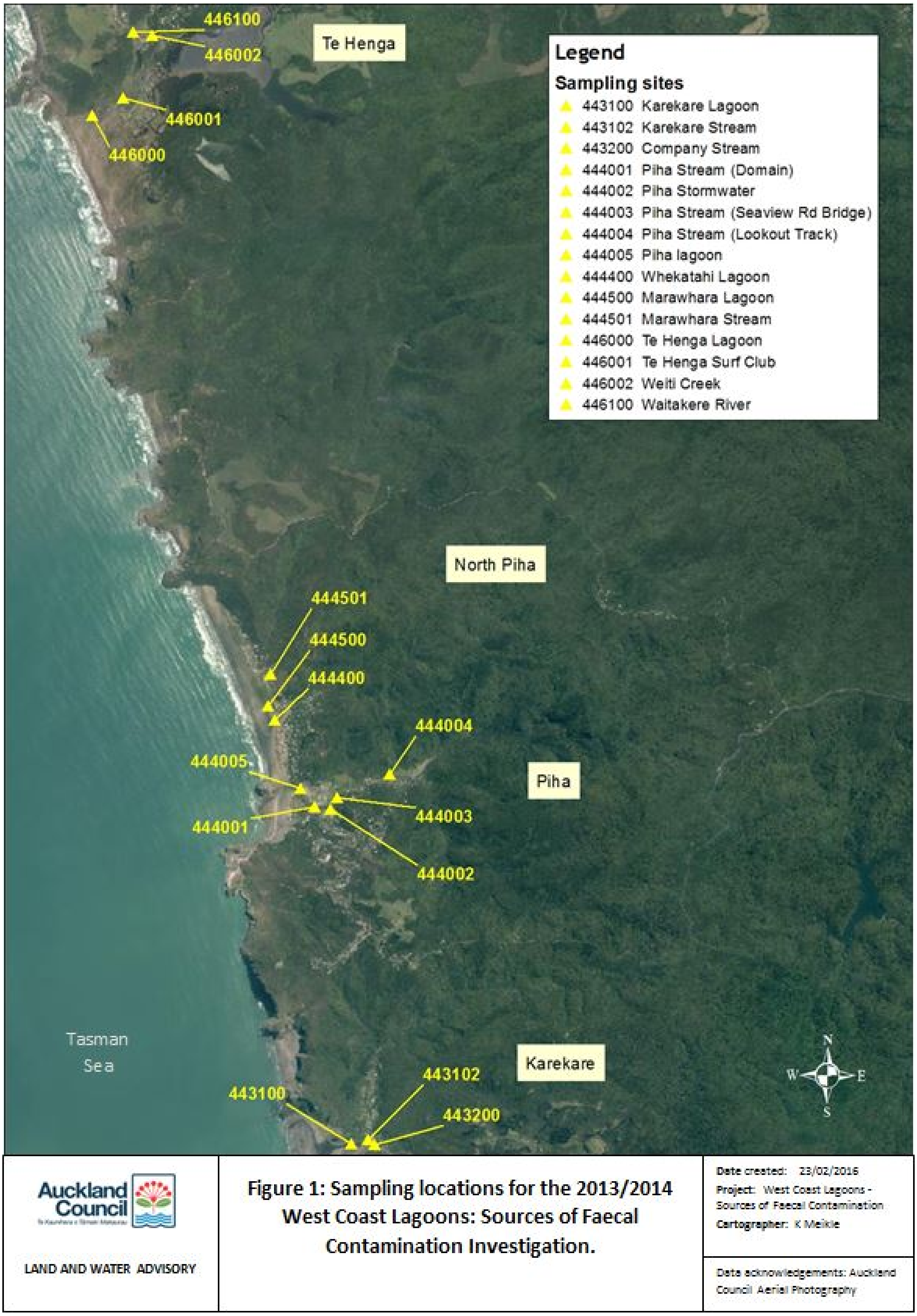


Figure 1 Overview map of study sites

2.4 Microbial Source Tracking (MST)

The samples collected for MST analysis were processed by Aqualab NZ Ltd within 24 hours of collection dependent on the *E. coli* test results. Those samples that had a corresponding microbiological sample >550 *E. coli*/100mL (i.e. red/action mode) were filtered through 0.45µm membrane filters until blocked. A buffer agent was then added and the filters were frozen for future MST analysis, a process that maintains the sample integrity for up to six months (Gilpin *et al*., 2013).

At the end of the Safeswim season, a subset of the frozen filters were selected and couriered to the Institute of Environmental Science and Research (ESR) laboratory, Christchurch, for MST analysis using the Polymerase Chain Reaction (PCR) method. This method of MST amplifies the DNA from host specific bacteria in the filtered water samples and tests for the presence of markers for the animal species requested. The markers requested in this investigation were for a general faecal marker and dog, bird, ruminant, horse and three human markers (BiADO, BacH and HumM3).

The filters that were selected for MST were selected because they were associated with elevated concentrations of *E. coli* in the water samples collected at the same time. The selection process was a pragmatic approach, where the requirement for information on sources was balanced with the fiscal constraints of the investigation. In general, the samples with concentrations above 550 *E. coli*/100mL were selected for MST analysis, however where there were high concentrations on consecutive days, the samples with the highest results were selected for MST analysis. This is consistent with previous studies, where the use of molecular techniques is more likely to yield useful results when faecal indicator bacteria are high (Cornelisen *et al*., 2012).

Interpreting MST results

MST results are reported on a scale from ‘extremely strong positive’ to ‘very weak positive’ for the general marker only. The ruminant marker is expressed as a percentage of the general marker for ‘fresh’ faecal sources. All other animal markers except the ruminant marker are reported as ‘present’, ‘present/not detected’ or ‘not detected’ for each animal marker based on Table 2 below. The ‘present/not detected’ result is interpreted as a weak faecal source at the limit of reporting.

Extremely strong positive general marker (GenBac) results are likely to indicate recent and high levels of faecal contamination. Conversely, very weak positive (at the limit of reporting) results indicate an aged, degraded or partially treated source. Only the GenBac results are reported on this semi-quantitative scale. If a high general faecal marker level is present but no specific animal marker is identified, the samples are interpreted as not consistent with fresh or untreated faeces from the sources tested (ESR 2013).

The markers chosen for analysis were Human (BiADO), Human (BacH), Human (HumM3), Canine (DogBac), Ruminant (BacR), Horse (Schill) and Avian (GFD). The BacH marker is more sensitive than the BiADO marker, but it has higher non-specificity than the BiADO marker with other animal species such as possum, dog, cat, rabbit, goat and chicken faecal sources. Therefore the BaCH marker cannot definitively show the faecal source is human (ESR 2013, pers. com. B Gilpin 2015). However the BiADO marker persists longer in the environment and is evidence of human (wastewater) contamination because it has low-level non-specificity with other animal markers such as possum, dog and waterfowl markers (pers. com. P Scholes 2014). HumM3 is the least sensitive human marker found only in samples with high levels of faecal contamination (pers. com. P Scholes 2014). It also has some non-specificity with other animal markers (including horse faecal matter) mentioned above.

When BacR is detected, it is reported using a percentage scale. This is based on the observation that in fresh ruminant faeces there is a consistent ratio between BacR and GenBac (about 10%). The other markers are present in fresh faeces at variable levels, so a similar ratio is not possible.

Table 2: Interpretation of the ESR MST results

Extremely strong positive	General faecal marker only
Very strong positive	General faecal marker only
Strong positive	General faecal marker only
Positive	General faecal marker only
Weak positive	General faecal marker only
Very weak positive	General faecal marker only
Present	Faecal source detected
Present/ND	Weak faecal source at the limit of reporting
Not Detected (ND)	Faecal source not detected

2.5 Rainfall records from the Piha rain gauge

Daily rainfall data (i.e. 24h daily total rainfall) for the 2013–2014 Safeswim season were obtained from the Auckland Council Research and Evaluation Team (RIMU). This data is recorded by the Auckland Council rain-gauge located near Piha Domain. Rainfall records were plotted against *E. coli* results for the lagoons over the 2013–2014 Safeswim season and the relationship assessed using linear regression.

2.6 Long-term trend for Piha Lagoon

In 2010 a major upgrade to the Piha Domain wastewater treatment system occurred, which included connecting the Returned Services Association (Piha RSA) and Bowling Club wastewater systems to it. To assess any effect of this upgrade on microbiological water quality in the lagoon, a trend analysis was performed on Piha Lagoon *E. coli* data.

A seasonal Kendall trend test was performed for Piha Lagoon *E. coli* data over twelve Safeswim seasons (2002–2003 to 2013–2014 (n=252)) using the National Institute of Freshwater and Atmosphere (NIWA) Trend and Equivalence software package (Version 4).

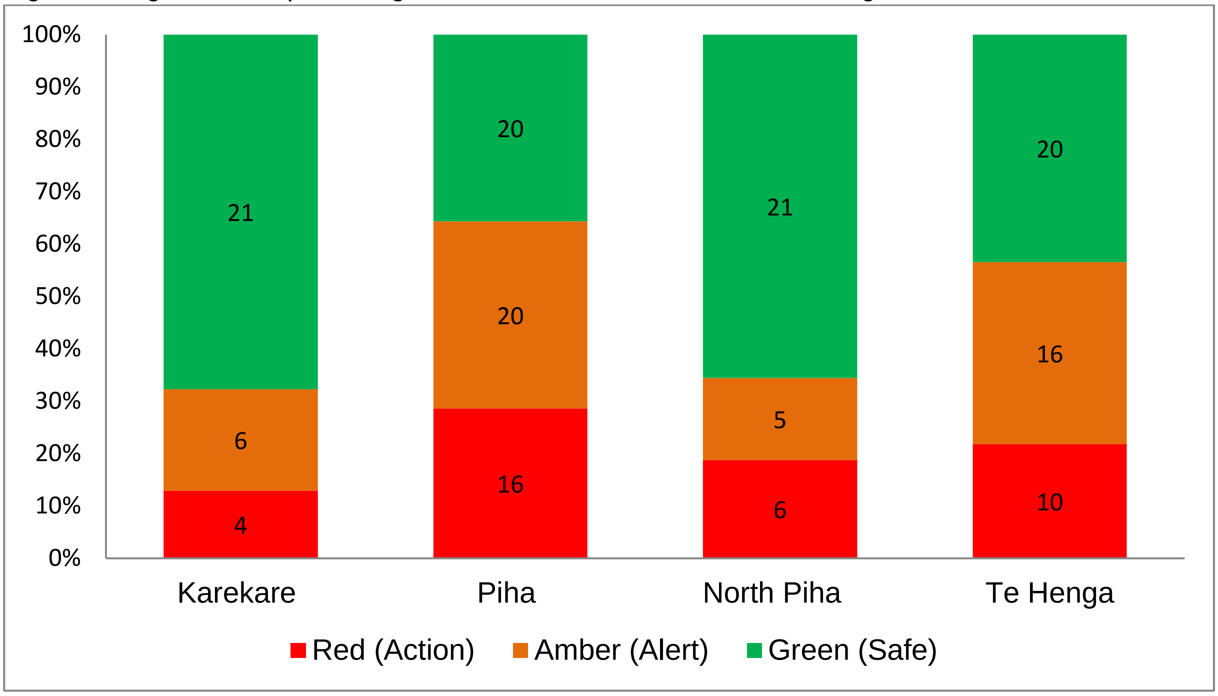
In addition a non-parametric Mann-Whitney one-way ANOVA was performed to measure any significant difference in the Piha Lagoon *E. coli* data before and after the upgrade of the Piha Domain wastewater treatment system.

3.0 Results

3.1 Safeswim results

Figure 2 shows the percentage of samples in the green/safe, amber/alert and red/action modes of the national guidelines over the 2013–2014 Safeswim season. The graph shows that Karekare and Piha Lagoons had 13% (N=4) and 29% (N=16) of samples in the red/action mode (requiring warning signage) respectively. North Piha and Te Henga lagoons had 19% (N=6) and 22% (N=10) of samples in the red/action mode respectively.

Figure 2: Lagoon mode percentages for the 2013–2014 Safeswim bathing beach season.



Note: The number of samples in each mode percentage is shown on the bar graph.

No correlation found between rainfall and *E. coli* results

A poor relationship existed between rainfall and *E. coli* results for summer 2013–2014 based on the linear regression analysis (Karekare (R^2 = 0.40), North Piha (R^2 = 0.02), Piha (R^2 = 0.02) and Te Henga (R^2 = 0.04)).

Rainfall records and the full Safeswim microbiological results for summer 2013–2014 are provided in Appendix D. The 2013-2014 season was an unusually dry summer and it is possible that extending the analysis to include data for other summers could potentially identify a stronger relationship, however such an analysis was beyond the scope of this investigation.

No trend for Piha Lagoon *E. coli* concentrations

A non-significant trend (p = 0.83) was found for Piha Lagoon *E. coli* concentrations over eleven bathing seasons between summer 2003–2004 and 2013–2014. Furthermore no significant difference (p = 0.88) was found by a Mann-Whitney one-way ANOVA test before and after the instalment of the upgraded Piha Domain wastewater system in December 2010.

3.2 Microbiological sampling results

Three-hundred and eight water samples were collected as part of this investigation (Table 3). Of the samples collected, 68 breached the red mode guideline (i.e. above 550 *E.coli*/100mL) and a further 75 samples were above the amber mode guideline (i.e. above 260 E.coli/100mL).

All of the four Safeswim sites breached the red mode guideline at least once; hence all of the sites were retested during the investigation. However, the majority of the red mode exceedances and retests were in the Piha Lagoon and Te Henga Lagoon catchments.

Table 3: Summary of the number and type of tests undertaken for each Lagoon. The amber and red columns refer to the number of tests that exceeded the MfE guidelines (See Appendix A) and MST refers to the number of samples that were analysed for faecal sources.

Site Name	Number of samples				
	Weekly	**Retests**	**Amber**	**Red**	**MST**
Karekare					
Karekare Lagoon	13	1	4	1	1
Karekare Stream	13	1	3	5	3
Company Stream	13	5	1	1	1
Piha					
Piha Lagoon	13	18	8	13	8
Piha Stream (Domain)	13	7	9	3	3
Piha Stormwater	13	9	7	14	9
Piha Stream (Seaview Rd Bridge)	13	9	7	3	1
Piha Stream (Lookout Track)	13	7	4	5	2
North Piha					
Marawhara Lagoon	13	8	2	6	6
Marawhara Stream	13	6	1	1	1
Whekatahi Lagoon	13	6	7	3	3
Te Henga					
Te Henga Lagoon	13	15	8	6	4
Te Henga Surf Club	13	7	5	1	1
Weiti Creek	13	7	4	3	3
Waitakere River	13	7	5	3	3
Total	**195**	**113**	**75**	**68**	**49**

Piha Lagoon and stormwater had the highest *E. coli* concentrations

Of the four lagoons, Piha had the highest *E. coli* concentrations (median 330 *E. coli*/100mL), including a sustained nine day period of high test results from 30 December 2013 to 8 January 2014. The Piha stormwater sampling site had the highest *E. coli* concentrations of all sampling sites (median 740 *E. coli*/100mL) and represents the largest source of microbiological contamination to the Piha Lagoon.

The *E. coli* concentrations in the Karekare Stream (median 325 *E. coli*/100mL) were greater than those observed in both the lagoon (135) and the Company Stream (75). This result indicates that the Karekare Stream represents the largest source of microbiological contamination to the Karekare Lagoon.

For North Piha, both the Marawhara and Whekatahi lagoons indicated high levels of microbiological contamination, but in the case of Marawhara, the concentration of *E. coli* was greater in the lagoon than the stream flowing into it (Table 4). Similarly at Te Henga, the *E. coli* concentrations in the lagoon were higher than three stream sites flowing into the lagoon, but the data suggest the Waitakere River may be the largest source of microbiological contamination for this lagoon.

Table 4: Summary statistics for the *E. coli* tests for each Lagoon.

Site Name	***E .coli* results**				
	N	**Minimum**	**Maximum**	**Mean**	**Median**
Karekare					
Karekare Lagoon	18	65	1500	258	135
Karekare Stream	14	70	1000	425	325
Company Stream	14	10	1400	186	75
Piha					
Piha Lagoon	31	110	24200	1994	330
Piha Stream (Domain)	20	110	1400	390	285
Piha Stormwater	22	310	8700	1396	740
Piha Stream (Seaview Rd Bridge)	22	65	1200	345	250
Piha Stream (Lookout Track)	20	30	3900	614	270
North Piha					
Marawhara Lagoon	21	10	17300	1264	190
Marawhara Stream	19	40	1400	181	110
Whekatahi Lagoon	19	10	6100	789	280
Te Henga					
Te Henga Lagoon	28	65	2500	586	320
Te Henga Surf Club	20	100	590	274	220
Weiti Creek	20	30	680	314	275
Waitakere River	20	90	1600	364	205
Total					

Note: The full results are presented in Appendix C.

3.3 Microbial source tracking results

The human marker HumM3 and the horse marker were assayed in this investigation, however these markers were not detected at any of the sampling sites and are not discussed further. The key points from the MST analyses are described below; the full MST results from ESR are provided in Appendix E.

Unidentified faecal sources most common in Karekare

Five samples from the Karekare Lagoon and tributaries were subject to MST analysis (Table 5). Despite high concentrations of *E. coli* and strong positive detections of the general faecal marker, no specific faecal source was identified for the samples from Karekare Stream (3 samples) and lagoon (1 sample).

Two human markers were identified in the single sample from the Company Stream that was subject to MST analysis (Table 5). This is strong evidence that on 30 December 2013 a human source of contamination was entering the Company Stream, but this signal was not detected in the lagoon sample collected on the same day. However, during the previous summer (2012–2013), Karekare Lagoon was contaminated by human and bird faecal sources (Noble, 2014).

Table 5: Karekare MST results summer 2013–2014.

Site	Date	*E. coli (MPN*/100 mL)	General marker	Faecal source
Company Stream	30/12/2013	1400	Very strong positive	Human (BiADO and BacH)
Karekare Lagoon	30/12/2013	1500	Very strong positive	Not detected
Karekare Stream	17/12/2013	870	Very strong positive	Not detected
Karekare Stream	23/12/2013	810	Very strong positive	Not detected
Karekare Stream	30/12/2013	1000	Strong positive	Not detected

Human faecal markers found at all Piha sampling sites

At the Piha Stream (Lookout Track) site, a weak human faecal source was detected for one of the two samples sent for MST analysis (Table 6). The BacH marker in the absence of the other two human markers can be interpreted as human, but may also indicate possum, cat or rabbit faecal sources (ESR 2013, pers. comm. P. Scholes, 2014). No faecal source was found in the only other source tracked sample at this sampling site.

The single sample source tracked at the Piha Stream (Seaview Rd Bridge) site had both human markers present on 30 December 2013. In addition, stormwater discharging to the Piha Stream from the Piha stormwater sampling site had both human markers present on the same day, which was accompanied by a human marker (BiADO) being detected in both downstream sites (Piha Domain and Lagoon). Collectively, this is very strong evidence of human wastewater contamination entering the Piha Stream and Lagoon on this occasion.

The general marker was detected (strong or very strong) in all of the nine Piha stormwater samples sent for MST analysis, but a faecal source could only be identified from two samples. In addition to the detection of the human markers discussed above, the human marker BiADO was detected in the stormwater discharge on 17 December 2013.

At the Piha Domain sampling site, human markers were found in two of the samples; the BiADO marker was detected on 30 December 2013 and the BacH marker on 5 March 2014. The third sample from the Piha Domain sent for MST analysis had a very strong positive for the general marker with avian the only source detected.

Piha Lagoon contaminated by multiple faecal sources

All eight of the samples from the Piha Lagoon tested positive for the general marker, with human, dog and bird markers identifying multiple sources of contamination in the lagoon (Table 6).

Four of eight samples sent for MST detected human markers. On 30 December 2013 the human BiADO marker was detected in all sampling sites except for the Piha Stream (Lookout Track) site. No other faecal sources were detected in the samples on this day. In addition, both human markers (BiADO and BacH) were present in the samples from the stormwater and Piha Stream (Seaview Rd Bridge) sites on 30 December 2013. These results are strong evidence of human wastewater contamination of the Piha Stream. Again, on 4 January 2014 both human markers were detected in the lagoon along with dog and bird markers.

Bird markers were also prevalent in the Piha Lagoon, being detected in five of the eight samples sent for MST analysis. In particular, on 1 January 2014 the bird marker was the only source identified and was associated with the second highest *E. coli* concentration of the investigation (12,000 *E. coli*/100mL) and a very strong positive for the general marker. Dog markers were found in the lagoon on two occasions and no source was detected on 6 and 28 January 2014.

For comparison, during the previous summer (2012–2013), human and bird faecal sources were detected in the Piha Lagoon (Noble 2014).

Table 6: Piha MST results for summer 2013–2014.

Site	Date	*E. coli* MPN/100 mL	General	Faecal source
Piha Stream (Lookout Track)	6/01/2014	1300	Weak positive	Not detected
Piha Stream (Lookout Track)	28/01/2014	3900	Positive	Weak human (BacH)
Piha Stream (Seaview Rd bridge)	30/12/2013	1200	Very strong positive	Human (BiADO and BacH)
Piha Stormwater	17/12/2013	2360	Very strong positive	Human (BiADO)
Piha Stormwater	30/12/2013	960	Very strong positive	Human (BiADO and BacH)
Piha Stormwater	6/01/2014	1100	Strong positive	Not detected
Piha Stormwater	20/01/2014	8700	Very strong positive	Not detected
Piha Stormwater	28/01/2014	4600	Very strong positive	Not detected
Piha Stormwater	17/02/2014	660	Very strong positive	Not detected
Piha Stormwater	4/03/2014	2100	Very strong positive	Not detected
Piha Stormwater	5/03/2014	1200	Very strong positive	Not detected
Piha Stormwater	10/03/2014	830	Very strong positive	Not detected
Piha Domain	30/12/2013	1400	Very strong positive	Human (BiADO)
Piha Domain	4/03/2014	590	Very strong positive	Bird
Piha Domain	5/03/2014	1100	Very strong positive	Human (BacH) and bird
Piha Lagoon	17/12/2013	2200	Very strong positive	Dog and bird
Piha Lagoon	30/12/2013	5200	Very strong positive	Human (BiADO)
Piha Lagoon	1/01/2014	12000	Very strong positive	Bird
Piha Lagoon	4/01/2014	>24200	Very strong positive	Human (BiADO and BacH), dog and bird
Piha Lagoon	6/01/2014	1200	Positive	Not detected
Piha Lagoon	28/01/2014	590	Very strong positive	Not detected
Piha Lagoon	4/03/2014	2600	Very strong positive	Human (BiADO) and bird
Piha Lagoon	5/03/2014	2200	Very strong positive	Human (BiADO) and bird

Human, dog and bird faecal sources were found at North Piha

Human, dog or bird markers were identified in the North Piha catchment at the Marawhara Lagoon site on five out of six source tracked samples (Table 7). Furthermore, the human markers were found in the absence of other animal markers on three different days. On 5 March 2014 this was a weak human BacH marker, which cannot definitively be interpreted as human as this marker can also indicate possum, cat or rabbit faecal sources (ESR, 2013). Bird and dog markers were also identified in the lagoon.

No faecal source could be found at any site on 30 December 2013, despite the strong to very strong positive detection of the general faecal marker at each site.

The previous summer (2012–2013), the North Piha catchment was contaminated by human, dog and bird faecal sources. The Marawhara Stream sampling site was contaminated by dog faecal sources and may also be contaminated by possum, cat, rabbit or weak human faecal sources at the limit of detection (Noble 2014).

Table 7: North Piha MST results for summer 2013–2014.

Site	Date	*E. coli* MPN/100 mL	General	Faecal source
Marawhara Stream	30/12/2013	1400	Very strong positive	Not detected
Whekatahi lagoon	30/12/2013	3400	Very strong positive	Not detected
Whekatahi lagoon	6/01/2014	1200	Very strong positive	Not detected
Whekatahi lagoon	5/03/2014	6100	Very strong positive	Dog and bird
Marawhara lagoon	30/12/2013	2400	Strong positive	Not detected
Marawhara lagoon	6/01/2014	1300	Strong positive	Human (BiADO) and dog
Marawhara lagoon	4/03/2014	1600	Strong positive	Weak human (BiADO)
Marawhara lagoon	5/03/2014	17300	Very strong positive	Bird and weak human (BacH)
Marawhara lagoon	6/03/2014	960	Very strong positive	Human (BiADO)
Marawhara lagoon	3/02/2014	610	Strong positive	Human (BacH)

Ruminant faecal contamination the dominant source at Te Henga

Ruminant faecal markers were the dominant source of recent (fresh) faecal contamination at Te Henga. The ruminant marker was detected at all sampling sites and was present in nine out of eleven samples source tracked (Table 8).

Ruminant faecal markers were found in both tributaries that flow into Te Henga Lagoon on all but one of the six source tracked samples and at times represented 100% of the general faecal marker for fresh faecal sources. The sample collected on the 19 February 2014 from Weiti Creek was the only source tracked sample from the tributaries that did not contain a ruminant faecal source. A bird marker was detected in this sample

Where ruminant markers were found in the samples from the Te Henga sampling sites, they were commonly associated with bird markers.

In the lagoon a mix of ruminant, dog and bird faecal markers were detected. Dog markers were found on every sampling occasion and bird markers on two out of four occasions. No human markers were detected at the Te Henga sites during the investigation.

The previous summer (2012–2013) Te Henga lagoon was contaminated by human, dog, ruminant and bird faecal material where ruminants were the dominant fresh faecal source (Noble 2014).

Table 8: Te Henga MST results summer 2013–2014. Note: the ruminant bacterial source is expressed as a percentage of the general marker for fresh sources.

Site	**Date**	***E. coli* MPN/100 mL**	**General**	**Faecal source**
Waitakere River	31/12/2013	610	Very strong positive	Ruminant (≤10%) and bird
Waitakere River	27/01/2014	1300	Very strong positive	Ruminant (10–50%) and bird
Waitakere River	10/02/2014	1600	Very strong positive	Ruminant (100%) and bird
Weiti Creek	31/12/2013	680	Positive	Ruminant (100%)
Weiti Creek	27/01/2014	590	Strong positive	Ruminant (10–50%)
Weiti Creek	19/02/2014	600	Very strong positive	Bird
Te Henga Surf Club	20/01/2014	590	Very strong positive	Ruminant (50%) and bird
Te Henga Lagoon	17/02/2014	2500	Very strong positive	Ruminant (≤1%) and dog
Te Henga Lagoon	19/02/2014	1400	Very strong positive	Ruminant (≤1%), dog and bird
Te Henga Lagoon	5/03/2014	1600	Very strong positive	Dog and bird
Te Henga Lagoon	27/01/2014	1300	Very strong positive	Ruminant (50%) and dog

4.0 Discussion

This section provides a case study covering the sampling sites in Piha Lagoon catchment: Piha Lagoon, Piha Stream (Domain), Piha Stormwater, Piha Stream (Seaview Rd Bridge) and Piha Stream (Lookout Track). It also:

- discusses the sources of faecal contamination in the four catchments at Karekare, Piha, North Piha and Te Henga investigated during summer 2013–2014
- evaluates the MST and microbiological results
- summarises historic reports where available and the limitations of the investigation.

4.1 Piha Lagoon catchment

Piha is a popular and iconic coastal environment, which is reflected in the large influx of visitors during the summer holiday season. The Piha Stream has its headwaters in the Waitākere Ranges, where it has one of the highest diversities of freshwater fish in the region. The catchment also has a lagoon, which is attractive for children to swim in to avoid the at-times dangerous surf. Piha Lagoon catchment has been chosen for a case study because its sampling sites often have extended periods of high *E. coli* levels exceeding the national guidelines. These levels require warning signs to be erected for up to a fortnight at a time.

Historic reports indicate long-term contamination of Piha Lagoon

Multiple reports, as far back as 1985, have recognised the levels of contamination of Piha Lagoon (Challis 1985, WCC 1994, 1995a, 1995b, 1996). Recommendations from these reports were to canvas the community for anecdotal evidence of wastewater contamination and declining water quality. Visual inspections were also made and some enforcement action was undertaken, but the evidence indicates that the problem has not been resolved.

In other unpublished Auckland Council reports human, dog and wildfowl markers were found in the Piha Lagoon (ESR 2008, 2009). In addition, fluorescent whitening agents, which indicate the presence of grey water, have been recorded in Piha Stream and the Glenesk Stream that is a tributary of Piha Stream (ELS 2011). The human adenovirus (pathogen) was also found in the Piha Lagoon (Leonard and van Duivenboden 2007).

Piha Lagoon sampling site had the highest median *E. coli* concentrations (330) and longest sustained period of elevated results of all of the lagoons during this summer's investigation. During late December and early January (2013–2014), Piha Lagoon had nine days of consecutive, high *E. coli* levels reaching the red/action mode of the national guidelines. This level of contamination has continued during the 2014–15 summer, where Piha Lagoon had 14 consecutive days of samples exceeding of the safe level of the national guidelines (unpublished Safeswim data). As a result, warning signs were in place for two weeks until *E. coli* concentrations returned to safe levels.

Piha stormwater site had the highest *E. coli* concentrations of all sampling sites

Piha stormwater sampling site had the highest median *E. coli* concentration (740 MPN/100mL) of all the sampling sites investigated in all four lagoon catchments, and the MST analysis detected only human faecal sources (although this was for only two of the seven samples tested). Nevertheless, this result indicates the presence of human faecal matter in this sub-catchment and suggests that this sub-catchment should be prioritised for further investigation and potentially on-site wastewater system management.

Human faecal markers consistently found at Piha sites

Human faecal markers were detected on six different sampling occasions in the Piha catchment. On 30 December 2013 all of the Piha sampling sites from which samples were subject to MST analysis site had human faecal markers present (Piha Stream (Lookout Track) site was not tested on this day). Furthermore, no other faecal sources were identified in the samples, providing strong evidence that human faecal contamination occurred on that day. There was a large rain event on the 30 December 2013 (30 mm in 48 hours (Appendix D), which may have overwhelmed on-site wastewater systems in the catchment.

Population influx may increase faecal contamination of Piha Lagoon

A morning peak of faecal coliform concentrations was identified during the peak summer holiday season months of 1983–1984, 1984–1985 and 1985–1986 (Challis, 1985). This is suggestive of a 'morning flush' effect caused by people using their bathroom facilities. This sent a pulse of high bacterial concentrations down the stream that took several hours to reach the lagoon, depending on flow rate and tidal conditions, but by mid-afternoon had usually dissipated (Challis 1985).

In the 2013–2014 summer, nine days of consecutive red mode exceedances of the national guidelines occurred requiring warning signage. This occurred during peak holiday season when the on-site wastewater systems may have become overloaded by the increased occupancy. A similar trend occurred the previous summer during the 2012–2013 bathing season with 11 consecutive days of red/action exceedances (unpublished Safeswim data).

The high *E. coli* concentrations over the peak summer months and detection of human markers in this study and by ESR (2014) provides strong evidence of human derived contamination in the Piha Lagoon. Piha has the highest housing density out of all of the lagoon catchments and poor design and maintenance of on-site wastewater systems are potential reasons given for these systems contributing to the poor water quality of the Piha Lagoon (Challis 1985, WCC 1994, 1995a, 1995b, 1996).

Piha Domain wastewater system discharge quality very good

Piha Domain wastewater system discharge quality for *E. coli* concentrations is of a very high quality (Appendix F). No significant difference of *E. coli* concentrations in the Piha Lagoon was found in tests before and after the instalment of the upgraded Piha Domain wastewater treatment plant in 2010 (p = 0.88, Mann-Whitney one-way ANOVA). This test was undertaken to investigate any effect of the full reticulation and upgrade of the Piha Domain ablution facilities in 2010, which service the library, campground, bowling club and Returned Services Association.

Whilst the discharge quality of the treatment plant is good, *E. coli* concentrations remain high in the Piha Lagoon and this analysis indicates that the treatment plant upgrade has had no detectable effect on the water quality of the lagoon. This suggests that the lagoon has been and continues to be contaminated by faecal sources other than those previously or currently captured by the treatment plant.

4.2 Human source in Karekare Lagoon tributary close to houses

Karekare Stream and the Company Stream are tributaries of Karekare Lagoon. Both human markers (BiADO and BacH) were found in the Company Stream site on 30 December 2013, which is strong evidence of human contamination. This was the only sample from the Company Stream that was subject to MST analysis, because in general the *E. coli* results from this site and Karekare Lagoon were low (median of 75 and 135 respectively). Four houses are in close proximity to the lower reaches of the Company Stream along with their on-site wastewater systems, although the low *E. coli* results for the Safeswim season would indicate that if there is a problem with the on-site wastewater systems at these houses, it is likely to be intermittent. However, there was significant rainfall on the 30 December 2013 (30 mm in 24 hours) that may have overwhelmed the on-site systems. Further testing in this catchment immediately following high rainfall events would be required to confirm whether this is an ongoing issue.

Notwithstanding the isolated issue in Company Stream, the *E. coli* results would indicate that the Karekare Stream represents the greatest source of microbiological contamination to the Karekare Lagoon. However, despite strong and very strong positive detections for the general marker from all five of the Karekare sites source tracked, no source markers were detected other than the result discussed above. It is possible that this is due to diluted, degraded or partially treated faecal sources that MST tools cannot currently detect. More than thirty houses are within 10m of the Karekare Stream and around 24 more separated from it only by Karekare Road (≈25m). However, identifying and tracking the source of the contamination in this stream will likely require further upstream sampling for *E. coli* and MST.

Historically, contamination of the Karekare Lagoon has been recognised since at least 1994, with on-site wastewater systems suspected as being the cause (WCC 1994, 1995a, 1995b, 1996).

4.3 North Piha catchment contaminated by human sources

All of the ten source tracked samples from the North Piha catchment showed strong or very strong positive detections for the general marker, although for four of the samples no source markers were detected.

Five of the six samples from the Marawhara Lagoon that were subject to MST analysis contained markers of human faecal contamination. However, on each occasion only one of the human markers were detected (BiADO three times and BacH twice). Whilst not 100% conclusive, the presence of human markers in five different samples collected during January, February and March 2014 is strong evidence of systemic contamination by a human source. In particular, the presence of the BiADO marker is interpreted as strong evidence of human contamination, albeit from an aged or degraded source, because this marker persists longer in the environment and has higher specificity than the other human markers (ESR 2013, pers. comm. P. Scholes 2014).

The source of the human contamination in the Marawhara Lagoon is unclear as the Marawhara Stream, which flows into the lagoon, had low *E. coli* concentrations throughout the investigation (110 *E. coli*/100mL). One sample underwent MST for the Marawhara Stream site during the investigation and no faecal source was detected, however in the previous summer (2012-13), a human (BacH) and dog marker was found on a single occasion. These results suggest that there could be another contribution of contamination to the lagoon that was not identified during this investigation. For example, there was a deepbore disposal field close to the lagoon at the time of this study that has since been replaced. Follow up investigations in the lagoon after this upgrade would be informative.

4.4 Livestock management required at Te Henga

The Te Henga Lagoon had the second highest median *E. coli* concentrations (320) of the lagoons during this investigation and this was accompanied by consistent and widespread detection of ruminant markers in the catchment. A ruminant source of faecal contamination was identified at all sampling sites, including on multiple occasions in the Waitakere River and Weiti Creek. On one occasion each of the tributaries had a ruminant faecal source accounting for up to 100% of the fresh faecal material. These results are consistent with a previous study, where ruminant sources were identified at the Te Henga Surf Club and lagoon sampling sites in summer 2012–13 (Noble 2014).

The relatively low rainfall during the past two summers suggests that direct stock access to Waitakere River and Weiti Creek is the likely cause of ruminant faecal contamination in the Te Henga catchment. This indicates that excluding stock from waterways at Te Henga will reduce ruminant bacterial contamination of the lagoon.

It should also be noted that bird and dog markers were frequently detected in the Te Henga catchment, in particular bird markers were detected in all three of the Waitakere River MST samples and dog markers in all four of the lagoon MST samples.

No human faecal sources were identified in Te Henga in this investigation. However, in 2012-13 summer, all three human markers (BiADO, BacH and HumM3) were detected in the lagoon on one occasion and the HumM3 and the BacH markers at the Te Henga Surf Club site on the same day. Whilst this is strong evidence of human faecal contamination, human contamination does not appear to be systemic.

4.5 Rainfall and *E. coli* concentrations are not correlated

No significant correlation could be found between rainfall and *E. coli* results at any of the lagoon (Safeswim) sampling sites over the 2013–14 bathing season. A similar outcome was found during summer 2012–13. There are isolated site-specific examples of elevated *E. coli* concentrations following instances of heavy rainfall (>10mm in a day), but equally there are examples of heavy rainfall that resulted in minimal contamination being detected.

The lack of a relationship with rainfall in the Safeswim data is likely a result of two key reasons. First, the Safeswim programme is not ‘event’ based and therefore not designed to detect the effects of rainfall on microbiological water quality. Second, contamination sources are spatially and temporally variable in nature, the distribution pathways of contamination are highly dynamic and the persistence of contamination in the environment (and hence the ability to detect it) is subject to complex biological and physicochemical processes (Boehm *et al.,* 2005). These issues combine to mean it is highly unlikely that a significant relationship with a single explanatory variable, such as rainfall, could be established.

4.6 Lagoons are susceptible to high levels of bacteria

Lagoons are warm, enclosed environments with fine, nutrient-rich sediments. Faecal indicator bacteria such as *E. coli* can persist and replicate in environments that are favourable, such as in fine sediment, sand and organic matter. This means that *E. coli* levels can be elevated in the absence of faecal contamination and thus give a false indication of public health risks (Solo-Gabriele *et al*., 2000, Verhougstraete *et al*., 2010). Furthermore, it has been demonstrated that stream sediments can act as reservoirs and secondary sources of *E. coli* that may later be re-mobilised in the environment. (Muirhead *et al.,* 2004; Jamieson *et al.,* 2005). Hence, persistence and reproduction in stream and lagoon sediments by *E. coli* could contribute to the elevated *E. coli* concentrations over the summer months.

If this is the case, then an option to reduce *E. coli* concentrations could be to manage the lagoons outlets to the sea to allow contaminated water out and fresh seawater in if or when water quality poses a serious health risk. However, this will have to be considered carefully due to potentially adverse ecological effects and the relative cost versus benefit. While opening the lagoon mouths to the sea may be possible (Tonkin and Taylor, 2015), this will not help reduce the source of fresh contamination. Furthermore, if it successfully reduced *E. coli* levels, it may be a disincentive to reduce those sources of fresh contamination.

Good bird habitat is located in the all four lagoons and their catchments, with birdlife observed on numerous occasions during the course of the investigation. It was therefore not unexpected when bird faecal contamination was identified in three of the lagoons.

Dog faecal contamination was found in three lagoons (Piha, North Piha and Te Henga), reflecting the areas where people have access to walk dogs along the lagoon margins. It is possible that rain or tidal action was mobilising bird and dog faecal material deposited along the lagoon margins and washing it into the lagoons. For example, on 2 January 2014 a spring tide occurred and high tides lasted several days. After this time Piha Lagoon had four days where the national guidelines were exceeded and bird and dog markers were present. During site visits for this investigation to Piha Lagoon, the presence of faecal material from dogs and birds below the high tide mark was noted. Dogs were also observed in the lagoons themselves.

4.7 All sites had occasions when no faecal source was detected

All lagoons had occasions of elevated concentrations of *E. coli* and all of the 49 samples sent for MST analysis were positive for the general faecal marker. The MST results indicated that faecal contamination originating from human, dog, bird and ruminant sources was present in one or more of the lagoons on multiple occasions. However, the biological source of contamination in 18 of the MST samples could not be detected by the MST analysis used in this investigation.

The presence of the general faecal marker without identifying specific source markers suggests that either other faecal sources (non-target animals) may be present, or that aged, degraded or partially treated faecal sources are present (ESR 2014). Such degradation of MST markers could be caused by treatment via on-site wastewater systems, dilution and irradiation by sunlight (pers. comm. B Gilpin 2013).

5.0 Conclusions

This investigation has showed a complex mix of microbiological contamination in the west coast lagoons. All of the lagoons had high concentrations of *E. coli* at times during the 2013-2014 summer and all 49 samples subject to MST analysis tested positive for the general faecal marker. A range of animal faecal sources were contaminating the west coast lagoons and their tributaries, including human, dogs, birds and ruminants, however all of the lagoons had occasions where the faecal source could not be detected.

Karekare

The sampling sites in the Karekare Lagoon catchment had moderate levels of *E. coli*, with a human source detected in one (of five) MST samples. This appeared to be associated with a rain event that may have overwhelmed the wastewater systems in the Company Stream catchment. In general, the investigation suggests the Karekare Stream is the greatest source of *E .coli* to the lagoon, but the study was unable to determine the biological source of this contamination.

Piha

The sampling sites in the Piha Lagoon catchment had the highest concentrations of *E. coli* of the study lagoons. The presence of human-derived faecal contamination was detected in 10 of the 23 samples that were sent for MST analysis. The Piha stormwater sampling site was consistently the most contaminated site in the whole investigation and likely represents the greatest source of *E. coli* to the Piha Lagoon. Contamination from dog and bird sources was consistently detected in the lower parts of the catchment.

North Piha

The sampling sites in the North Piha catchment had moderate levels of *E. coli*. There was strong evidence of human contamination in the Marawhara Lagoon site as human markers were detected in five (of six) MST samples. The geographic source of this contamination was unclear and it is likely that there is an unknown contamination source in this lagoon that was not sampled during this investigation.

Te Henga

The sampling sites in the Te Henga lagoon catchment generally had the second highest concentrations of *E. coli* of the study lagoons. Ruminant sources of faecal contamination were widespread and common during the course of this investigation, suggesting that livestock management could reduce the level of contamination in the catchment. However, bird and dog sources were also common in this catchment.

6.0 Recommendations

To better manage the faecal contamination of the west coast lagoons at Karekare, Piha, North Piha and Te Henga a range of recommendations are presented below:

- Investigate and improve (where appropriate) the on-site wastewater (septic) systems and their maintenance in all Piha, North Piha and Karekare lagoon catchments.
- Improve septic system management where human faecal contamination has been identified in the Piha stormwater sub-catchment, particularly on Seaview Road and Glenesk Road.
- Investigate options for improving dog and bird control around all of the lagoons, including encouraging dog owners to pick-up after their dogs and to not feed the birds.
- Improve livestock and riparian management in the Te Henga catchment, including the exclusion of stock from the Waitakere River and Weiti Creek tributaries.
- Consider the placement of permanent warning signs to inform the public about the chronic water quality problems in the lagoons and explain the potential health risks of swimming in the lagoons until the water quality is improved.
- Investigate potential contamination sources in the Marawhara Lagoon, including a wastewater disposal field located between the Marawhara Stream and Marawhara Lagoon sampling sites.
- Consider a trial of opening one of the lagoons to the sea to facilitate flushing at high tide. Such a trial would require comprehensive monitoring to assess its effectiveness.
- Investigate the role of bacterial replication and survival to the high microbiological tests results from the lagoons.

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Appendix A Safeswim sampling and grading

Karekare, Piha, North Piha and Te Henga lagoons have been monitored under the MfE 2003 national guidelines since summer 2003–2004. Water samples are analysed weekly from November until the end of March each year for the level of the faecal indicator bacteria *Escherichia coli (E. coli),* which provides an indication of the potential health risk associated with swimming in the lagoons. Two sampling sites are monitored at Karekare (one in the lagoon and one at the confluence of Karekare and Company streams that feed into the lagoon) and one site in each of the other lagoons.

Under the national guidelines the last five years of results (i.e. ≈ 100 data points) can be used to generate a Microbiological Assessment Category. This provides a measurement of the actual water quality over time (MfE 2003). The Hazen calculation method is used in accordance with the national guidelines to determine the 95th percentile of the dataset for each lagoon. Refer to Table 1 below for Microbiological Assessment Category ranges for freshwater.

Table 9: Microbiological Assessment Category ranges for freshwater.

A	Sample 95 percentile ≤ 130 *E. coli* /100 mL
B	Sample 95 percentile 131–260 *E. coli* /100 mL
C	Sample 95 percentile 261–550 *E. coli* /100 mL
D	Sample 95 percentile > 550 *E. coli* /100 mL

Source: (MfE 2003)

All of the lagoons have a Microbiological Assessment Category of ‘D’ under this criteria indicating they have regular exceedances of the national guidelines. This means that they would get a ‘Poor’ or ‘Very Poor’ Suitability for Recreational Grade. Under the national guidelines the recommendation for these locations is to: “Avoid swimming, as there are direct discharges of faecal material. Permanent signage will be erected at the beach stating that swimming is not recommended.”

Samples are analysed by Aqualab NZ Ltd and reported by Council. Amber and red exceedances require re-tests until results return to the green/surveillance mode. Red/action exceedances require public health warning signs to be erected until results return to the green/surveillance mode. Table 1 below shows the national guidelines trigger levels for each mode.

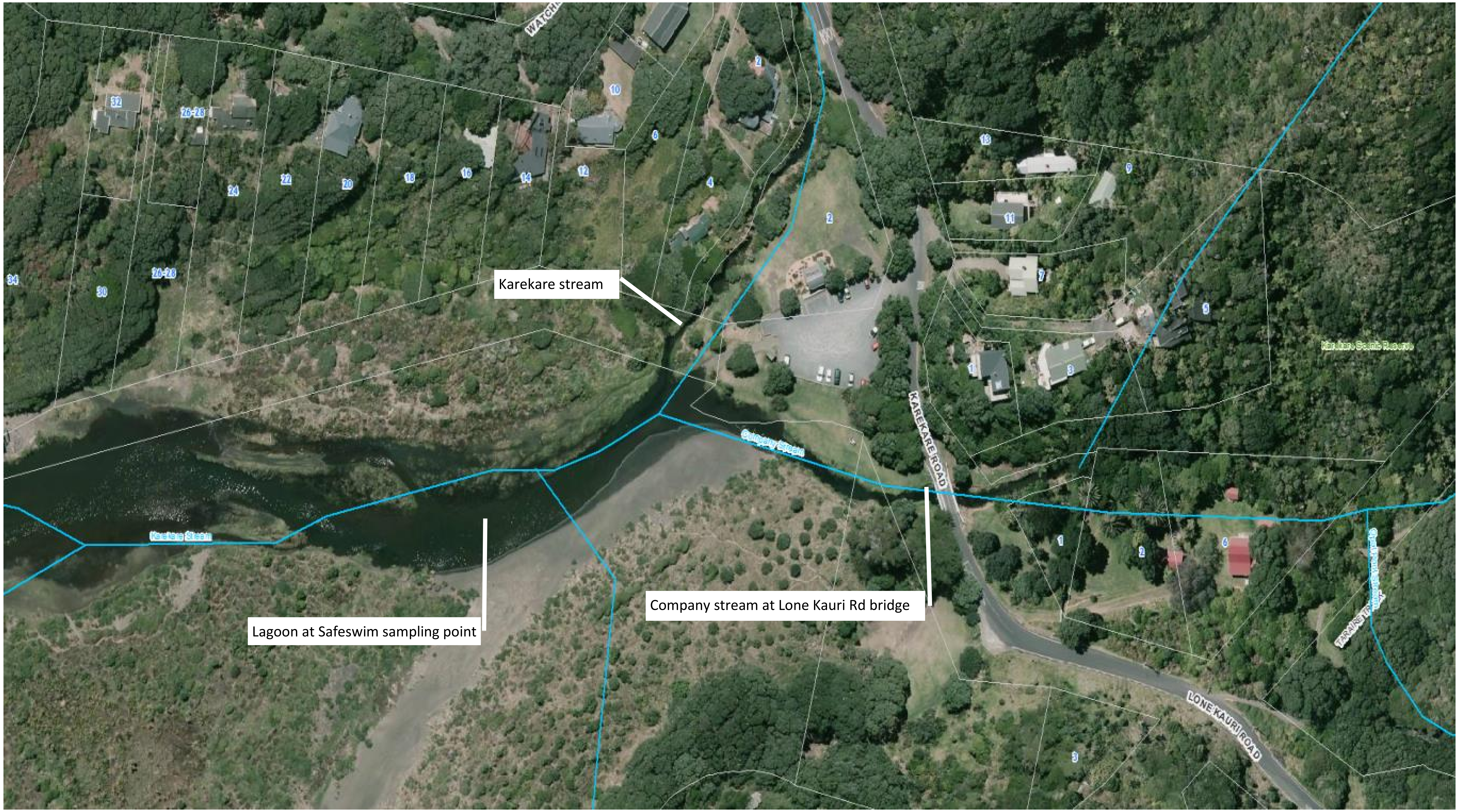
Table 10: Freshwater trigger levels (modes) from the 2003 MfE national guidelines.

Freshwater (*E. coli* /100mL)	Mode
Single sample ≤ 260	Green/Safe — Continue with routine sampling.
Single sample > 260 ≤ 550	Amber/Alert — Sampling increased to daily.
Single sample > 550	Red/Action — Daily sampling continues and Council places warning signage until levels return to green/safe mode.

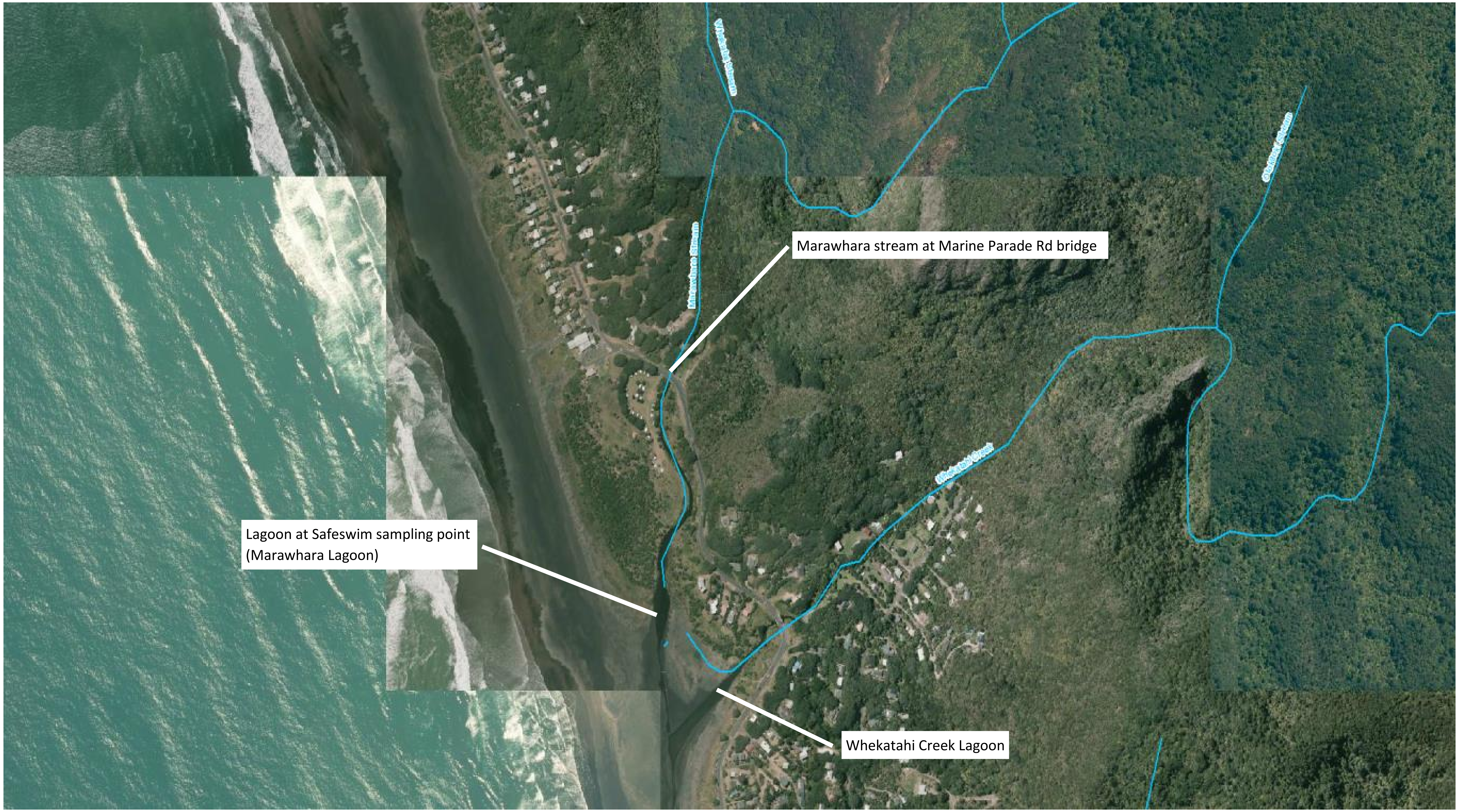
Source: (MfE 2003)

Appendix B Site locations

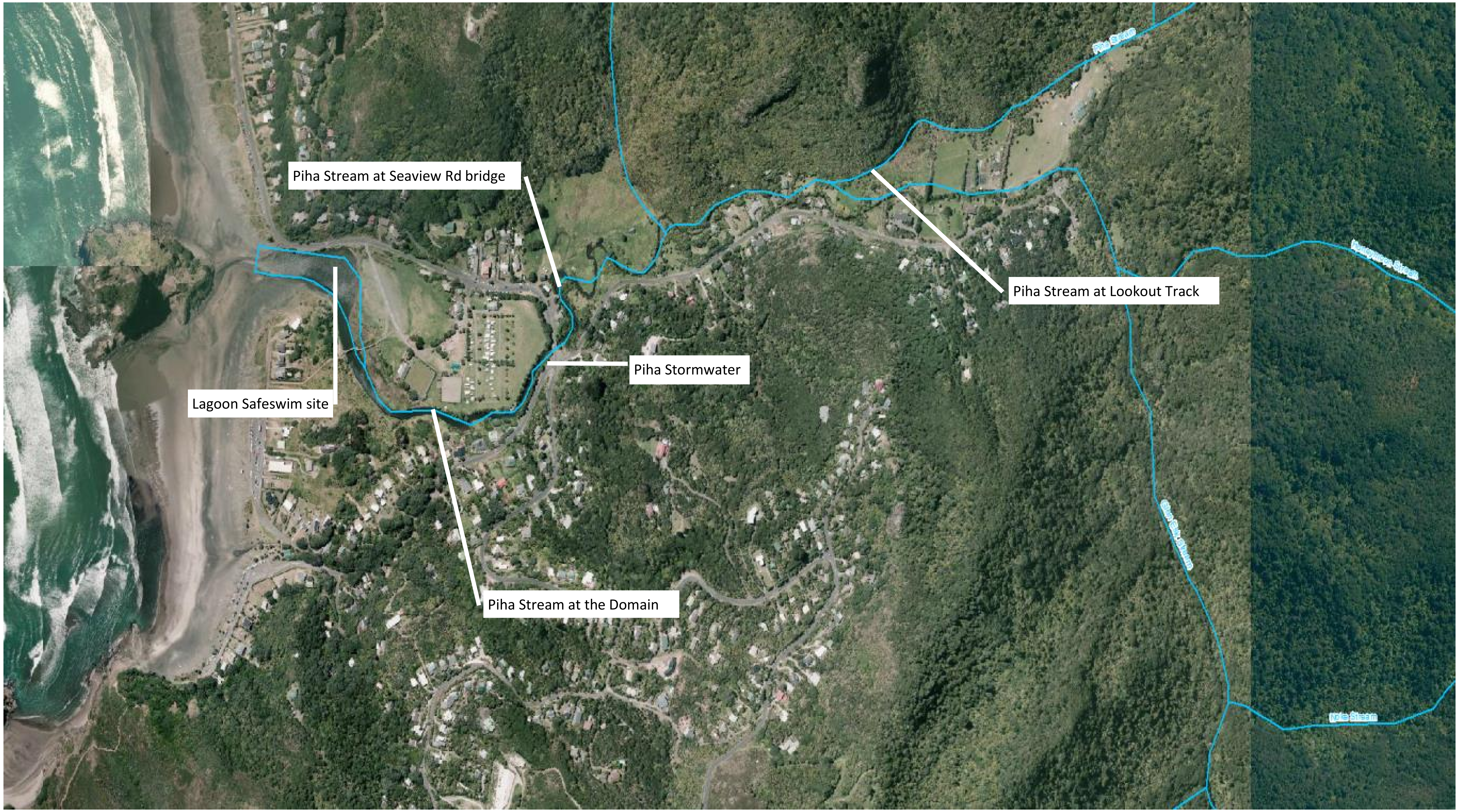
Karekare



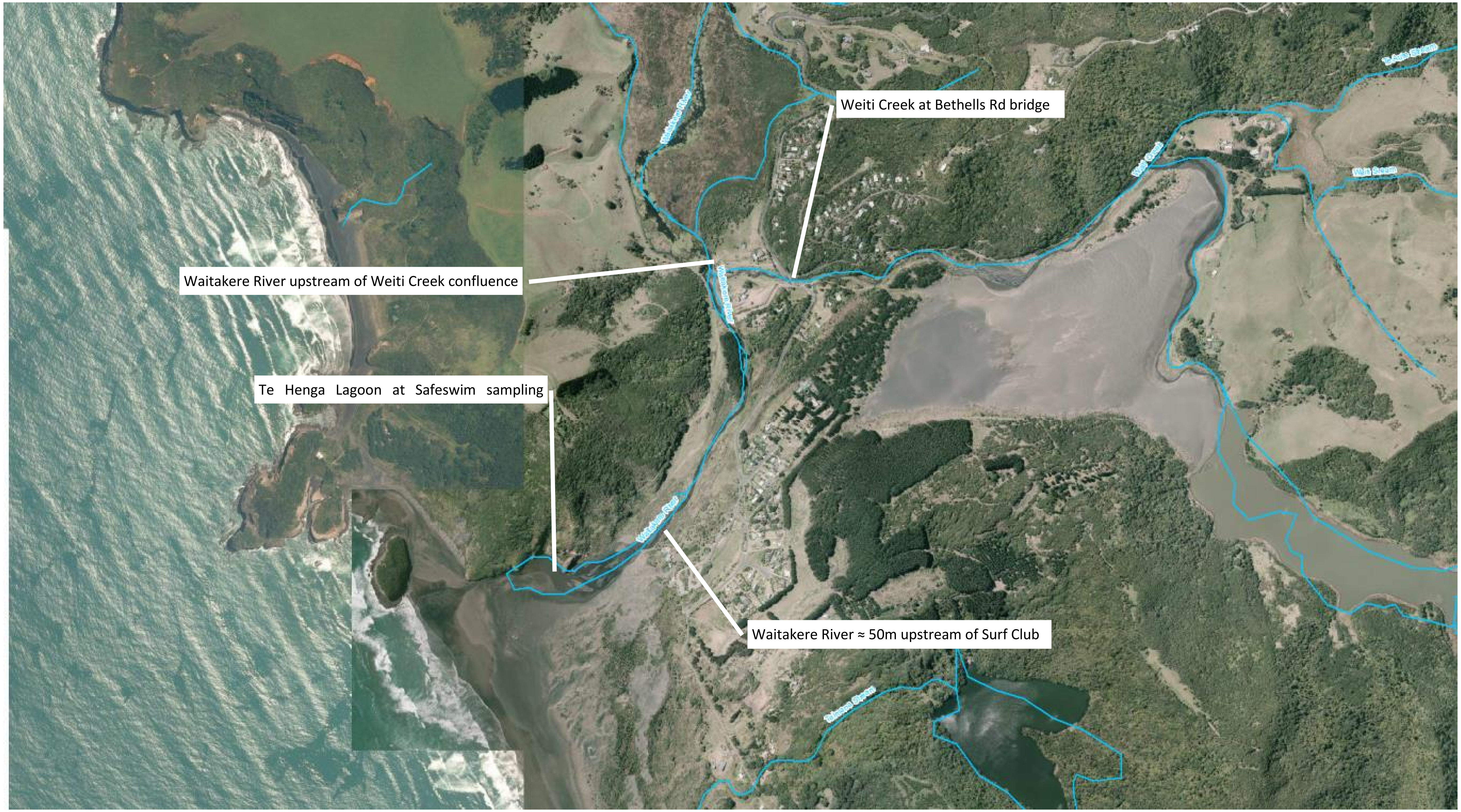
North Piha


Marawhara stream at Marine Parade Rd bridge
Lagoon at Safeswim sampling point (Marawhara Lagoon)
Whekatahi Creek Lagoon

Piha


Piha Stream at Seaview Rd bridge
Piha Stream at Lookout Track
Piha Stormwater
Lagoon Safeswim site
Piha Stream at the Domain

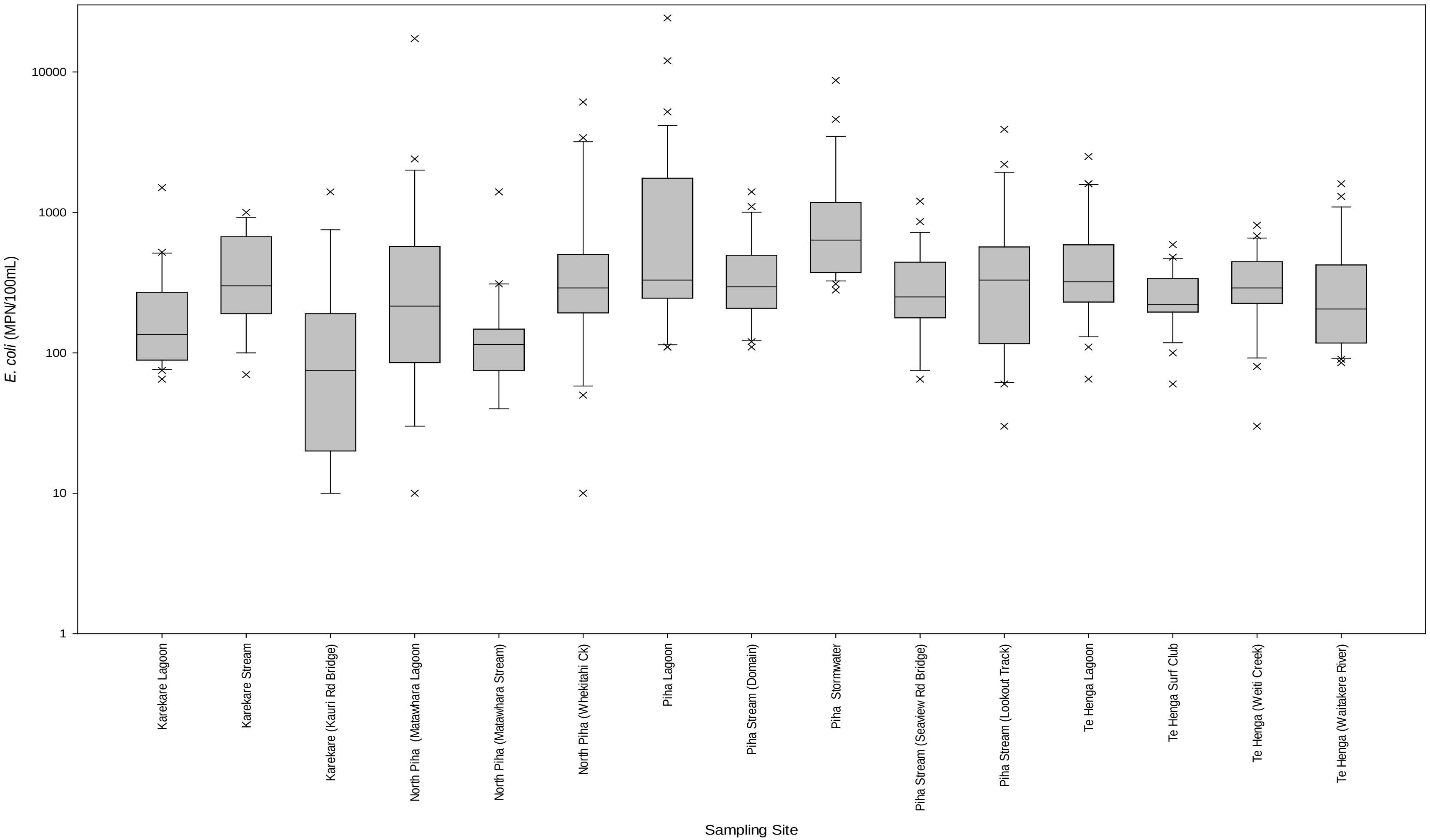
Te Henga


Weiti Creek at Bethells Rd bridge
Waitakere River upstream of Weiti Creek confluence
Te Henga Lagoon at Safeswim sampling
Waitakere River ≈ 50m upstream of Surf Club

Appendix C *E. coli* concentrations for all sites

Date	Company Stream	Karekare Stream	Karekare Lagoon	Whekatahi Lagoon	Marawhara Stream	Marawhara Lagoon	Piha Stream (Lookout Track)	Piha Stream (Seaview Rd Bridge)	Piha Stormwater	Piha Stream (Domain)	Piha Lagoon	Weiti Creek	Waitakere River	Te Henga Surf Club	Te Henga Lagoon
16/12/2013												240	100	160	110
17/12/2013	10	870	65	230	150	110	130	240	2360	270	2200				
18/12/2013							65	65	340	120	240				
23/12/2013	120	810	520	280	50	100	210	170	600	200	230	490	110	170	130
24/12/2013			240												
30/12/2013	1400	1000	1500	3400	1400	2400	520	1200	960	1400	5200				
31/12/2013	130	670	270	500	300	460	490	420	380	410	1700	680	610	420	390
1/01/2014			130			190		490	340		12000				1600
2/01/2014								450	390		2000	350	150	230	260
3/01/2014											1800				
4/01/2014											24200				
5/01/2014											1200				
6/01/2014	320	380	450	1200	75	1300	1300	370	1100	490	1200	430	180	280	520
7/01/2014			85	530	110	320	680	280	370	280	600				250
8/01/2014						250	280	200	980	510	110				
13/01/2014	75	300	160	190	120	85	380	250	2200	210	330	120	200	200	230
14/01/2014											310				
20/01/2014	50	190	110	200	140	240	65	580	8700	160	260	230	440	590	240
21/01/2014															
27/01/2014												590	1300	480	1300
28/01/2014	75	560	290	50	40	85	3900	200	4600	350	590	380	320	200	1100
29/01/2014			85				880	75	610	130	290	260	310	180	65
											130				
3/02/2014	20	70	100	300	120	610	2200	860	310	280	250	210	210	100	250
4/02/2014				170	40	70									
10/02/2014	140	120	75	220	120	190	30	120	520	300	310	350	1600	260	230
11/02/2014											320				
12/02/2014											280				
17/02/2014	50	210	120	130	110	30	60	110	660	280	160	230	120	210	2500
18/02/2014												290	140	440	730
19/02/2014												600	430	200	1400
20/02/2014												290	170	200	380
21/02/2014															230
24/02/2014	10	170	110	500	75	170	75	250	340	310	120	230	420	330	490
25/02/2014															280
26/02/2014															530
27/02/2014															
3/03/2014												200	95	250	540
4/03/2014	190	350	140	310	90	1600	150	400	2100	590	2600				320
5/03/2014				6100	210	17300	260	550	1200	1100	2200				1600
6/03/2014				400	110	960	160	230	820	290	390	80	90	210	160
7/03/2014				270	140	65					110				
10/03/2014	20	250	190	10	40	10	440	75	830	110	360	30	290	360	320
11/03/2014											110				260

Figure 3: Summary of *E. coli* concentrations all sampling sites.



Appendix D 2013–2014 Safeswim results and rainfall

E. coli **(MPN/100mL) and rainfall (mm/day) results for the 2013–2014 Safeswim season.**

NB: Blank cells show where no sampling was undertaken. Rainfall from council's Piha rain gauge. See Appendix A for explanation of the green, amber and red modes highlighted.

Date	Rainfall (mm/day)	Karekare Lagoon	North Piha Lagoon	Piha Lagoon	Te Henga Lagoon
4/11/2013	0.5	200	50	190	
5/11/2013	0				240
6/11/2013	19				
7/11/2013	4.5				
8/11/2013	9				
9/11/2013	0.5				
10/11/2013	0				
11/11/2013	0				160
12/11/2013	0	50	40	270	
13/11/2013	0			10	
14/11/2013	0				
15/11/2013	0				
16/11/2013	0				
17/11/2013	0				
18/11/2013	0				
19/11/2013	0	720	10	280	120
20/11/2013	11.5	3400		2100	
21/11/2013	0.5	500		500	
22/11/2013	0	85		100	
23/11/2013	0				
24/11/2013	0				
25/11/2013	0	120	20	170	300
26/11/2013	1				190
27/11/2013	0				
28/11/2013	8				
29/11/2013	10				
30/11/2013	1.5				
1/12/2013	0.5				
2/12/2013	0.5				
3/12/2013	0	100	75	200	400
4/12/2013	0				4100
5/12/2013	39.5				1200
6/12/2013	17.5				1700
7/12/2013	0				390
8/12/2013	2.5				120
9/12/2013	7				160
10/12/2013	0	160	330	470	
11/12/2013	0.5		240	190	
12/12/2013	0				
13/12/2013	0				
14/12/2013	0				

15/12/2013	0				
16/12/2013	0				110
17/12/2013	0	65	110	2200	
18/12/2013	0.5			240	
19/12/2013	0				
20/12/2013	1				
21/12/2013	1				
22/12/2013	0				
23/12/2013	0	520	100	230	130
24/12/2013	0	240			
25/12/2013	0				
26/12/2013	6				
27/12/2013	4				
28/12/2013	0				
29/12/2013	0				
30/12/2013	29.5	1500	2400	5200	
31/12/2013	2.5	270	460	1700	390
1/01/2014	0	130	190	12000	1600
2/01/2014	0.5			2000	260
3/01/2014	0			1800	
4/01/2014	0			>24200	
5/01/2014	0			1200	
6/01/2014	13	450	1300	1200	520
7/01/2014	0.5	85	320	600	250
8/01/2014	0		250	110	
9/01/2014	0				
10/01/2014	2				
11/01/2014	0				
12/01/2014	0	160	85	330	230
13/01/2014	0			310	
14/01/2014	0			450	
15/01/2014	0			340	
16/01/2014	0			540	
17/01/2014	0			200	
18/01/2014	0.5				
19/01/2014	0	110	240	260	240
20/01/2014	0				
21/01/2014	3.5				
22/01/2014	6.5				
23/01/2014	1				
24/01/2014	0.5				
25/01/2014	0				
26/01/2014	0				1300
27/01/2014	13	290	85	590	1100
28/01/2014	0	85		290	65
29/01/2014	2.5			130	
30/01/2014	0				
31/01/2014	0				

1/02/2014	0				
2/02/2014	0	100	610	250	250
3/02/2014	0		70		
4/02/2014	0				
5/02/2014	0				
6/02/2014	0				
7/02/2014	0				
8/02/2014	0.5				
9/02/2014	3	75	190	310	230
10/02/2014	0			320	
11/02/2014	0			280	
12/02/2014	0			390	
13/02/2014	2.5			340	
14/02/2014	0			320	
15/02/2014	1			220	
16/02/2014	1.5				
17/02/2014	0	120	30	160	2500
18/02/2014	0				730
19/02/2014	0				1400
20/02/2014	0				380
21/02/2014	0				230
22/02/2014	0				
23/02/2014	0	110	170	120	490
24/02/2014	1				280
25/02/2014	0				530
26/02/2014	0				480
27/02/2014	0				130
28/02/2014	0				
1/03/2014	0				
2/03/2014	0				540
3/03/2014	0	140	1600	2600	320
4/03/2014	1		17300	2200	1600
5/03/2014	2		960	390	160
6/03/2014	1.5		65	110	
7/03/2014	0				
8/03/2014	0				
9/03/2014	0	190	10	360	320
10/03/2014	0			110	260
11/03/2014	0				
12/03/2014	0				
13/03/2014	0				
14/03/2014	0				
15/03/2014	0				
16/03/2014	40.5	270	350	1020	520
17/03/2014	3.5	85	280	310	130
18/03/2014	0		30	170	
19/03/2014	0				
20/03/2014	0				

21/03/2014	0.5				
22/03/2014	0				
23/03/2014	0				250
24/03/2014	5	590	75	1300	
25/03/2014	0	260		360	
26/03/2014	0.5			170	
27/03/2014					
28/03/2014					

Appendix E Microbial Source Tracking Report

Institute of Environmental Science & Research Limited
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protecting people and their environment through science

6 June 2014

To: Andrew Noble
Auckland Council
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Auckland

Email: Andrew.Noble@aucklandcouncil.govt.nz
Purchase Order 3000147856

From: Dr Brent Gilpin
ESR Christchurch Science Centre
PO Box 29181
CHRISTCHURCH

REPORT ON FAECAL SOURCE TRACKING ANALYSIS – WEST LAGOONS & STREAMS

The following water samples were received on 30th April and 7th May 2014 and were analysed for faecal source PCR markers.

ESR Number	Client Reference	Sample Details	*E.coli* MPN/100ml
CMB140345	18488/5	Karekare Stream	870
CMB140346	18488/12	Piha Lagoon	2200
CMB140347	18488/7	Piha Stormwater	2360
CMB140348	18488/18	Karekare Stream	810
CMB140349	18488/49	Karekare Lagoon	1500
CMB140350	18488/50	Karekare carpark	1400
CMB140351	18488/28	Karekare (Kauri Rd Bridge)	1400
CMB140352	18488/29	Karekare Stream	1000
CMB140353	18488/48	Piha Lagoon	5200
CMB140354	18488/30	Piha Domain	1400
CMB140355	18488/31	Piha Stormwater	960
CMB140356	18488/32	Piha Seaview Rd Bridge	1200
CMB140357	18488/47	North Piha Lagoon	2400
CMB140358	18488/34	North Piha Marine Pde Bridge	1400

cont.

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ESR Number	Client Reference	Sample Details	*E.coli* MPN/100ml
CMB140359	18488/35	North Piha Whekitahi Ck	3400
CMB140360	18488/37	Bethells (Weiti Ck)	680
CMB140361	18488/38	Bethells (Waitakere River)	610
CMB140362	18535/8	Piha Lagoon	12000
CMB140363	18535/11	Piha Lagoon	24200
CMB140364	18535/37	Piha Lagoon	1200
CMB140365	18535/19	Piha Stormwater	1100
CMB140366	18535/21	Piha Look Out Track	1300
CMB140367	18535/38	North Piha Lagoon	1300
CMB140368	18535/23	North Piha Whekitahi Ck	1200
CMB140369	18535/49	Bethells Surf Club	590
CMB140370	18535/55	Piha Stormwater	8700
CMB140371	18535/61	Bethells (Weiti Ck)	590
CMB140372	18535/62	Bethells (Waitakere River)	1300
CMB140373	18535/83	Piha Lagoon	590
CMB140374	18535/67	Piha Stormwater	4600
CMB140375	18535/69	Piha Look Out Track	3900
CMB140376	18667/12	North Piha Lagoon	610
CMB140377	18667/37	Bethells Lagoon	2500
CMB140378	18667/32	Piha Stormwater	660
CMB140379	18667/45	Bethells Lagoon	1400
CMB140380	18667/43	Bethells (Weiti Ck)	600
CMB140381	18763/12	Piha Lagoon	2600
CMB140382	18763/6	Piha Domain	590
CMB140383	18763/7	Piha Stormwater	2100
CMB140384	18763/13	North Piha Lagoon	1600
CMB140385	18763/20	Piha Lagoon	2200
CMB140386	18763/14	Piha Domain	1100
CMB140387	18763/15	Piha Stormwater	1200
CMB140388	18763/21	North Piha Lagoon	17300
CMB140389	18763/19	North Piha Whekitahi Ck	6100
CMB140390	18763/31	Bethells Lagoon	1600
CMB140391	18763/32	North Piha Lagoon	960
CMB140392	18763/41	Piha Stormwater	830
CMB140454	18535/63	Bethells Lagoon	1300
CMB140455	18667/17	Bethells Waitakere River	1600

Results of PCR analysis:

ESR No	Sampled	*E.coli*	General GenBac	Human BacH	Human BiADO	Human HumM3	Ruminant BacR	Dog DogBac	Bird GFD	Horse	Overall Conclusion
CMB140346	Piha Lagoon, 17/12/2013	2200	very strong positive	ND	ND	ND	ND	present	present	ND	Faecal contamination – dog & avian sources
CMB140353	Piha Lagoon, 30/12/2013	5200	very strong positive	ND	present	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140362	Piha Lagoon, 1/01/2014	12000	very strong positive	ND	ND	ND	ND	ND	present	ND	Faecal contamination – avian source
CMB140363	Piha Lagoon, 4/01/2014	24200	very strong positive	present	present	ND	ND	present	present	ND	Faecal contamination – human, dog & avian sources
CMB140364	Piha Lagoon, 6/01/2014	1200	positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140373	Piha Lagoon, 28/01/2014	590	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140381	Piha Lagoon, 4/03/2014	2600	very strong positive	ND	present	ND	ND	ND	present	ND	Faecal contamination – human & avian sources
CMB140385	Piha Lagoon, 5/03/2014	2200	very strong positive	ND	present	ND	ND	ND	present	ND	Faecal contamination – human & avian sources
CMB140347	Piha Stormwater, 17/12/2013	2360	very strong positive	ND	present	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140355	Piha Stormwater, 30/12/2013	960	very strong positive	present	present	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140365	Piha Stormwater, 6/01/2014	1100	strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140370	Piha Stormwater, 20/01/2014	8700	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140374	Piha Stormwater, 28/01/2014	4600	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140378	Piha Stormwater, 17/02/2014	660	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140383	Piha Stormwater, 4/03/2014	2100	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140387	Piha Stormwater, 5/03/2014	1200	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140392	Piha Stormwater, 10/03/2014	830	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source

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ESR No	Sampled	*E.coli*	General GenBac	Human BacH	Human BiADO	Human HumM3	Ruminant BacR	Dog DogBac	Bird GFD	Horse	Overall Conclusion
CMB140357	North Piha Lagoon, 30/12/2013	2400	strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140367	North Piha Lagoon, 6/01/2014	1300	strong positive	ND	present	ND	ND	present	ND	ND	Faecal contamination – human & dog sources
CMB140376	North Piha Lagoon, 3/02/2014	610	strong positive	present	ND	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140384	North Piha Lagoon, 4/03/2014	1600	strong positive	ND	present / ND	ND	ND	ND	ND	ND	Faecal contamination – weak indication human source
CMB140388	North Piha Lagoon, 5/03/2014	17300	very strong positive	present / ND	ND	ND	ND	ND	present	ND	Faecal contamination – avian & weak indication human
CMB140391	North Piha Lagoon, 6/03/2014	960	very strong positive	ND	present	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140359	North Piha Whekitahi Ck, 30/12/2013	3400	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140368	North Piha Whekitahi Ck, 6/01/2014	1200	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140389	North Piha Whekitahi Ck, 5/03/2014	6100	very strong positive	ND	ND	ND	ND	present	present	ND	Faecal contamination – dog & avian sources
CMB140366	Piha Look Out Track, 6/01/2014	1300	weak positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140375	Piha Look Out Track , 28/01/2014	3900	positive	present / ND	ND	ND	ND	ND	ND	ND	Faecal contamination – weak indication human source
CMB140354	Piha Domain, 30/12/2013	1400	very strong positive	ND	present	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140382	Piha Domain, 4/03/2014	590	very strong positive	ND	ND	ND	ND	ND	present	ND	Faecal contamination – avian source
CMB140386	Piha Domain, 5/03/2014	1100	very strong positive	present	ND	ND	ND	ND	present	ND	Faecal contamination – human & avian sources
CMB140356	Piha Seaview Rd Bridge, , 30/12/2013	1200	very strong positive	present	present	ND	ND	ND	ND	ND	Faecal contamination – human source
CMB140358	North Piha Marine Pde Bridge, 30/12/2013	1400	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source

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ESR No	Sampled	*E.coli*	General GenBac	Human BacH	Human BiADO	Human HumM3	Ruminant BacR	Dog DogBac	Bird GFD	Horse	Overall Conclusion
CMB140360	Bethells (Weiti Ck), 31/12/2013	680	positive	ND	ND	ND	present 100%	ND	ND	ND	Faecal contamination – ruminant source
CMB140371	Bethells (Weiti Ck), 27/01/2014	590	strong positive	ND	ND	ND	present 10 - 50%	ND	ND	ND	Faecal contamination – ruminant source
CMB140380	Bethells (Weiti Ck), 19/02/2014	600	very strong positive	ND	ND	ND	ND	ND	present	ND	Faecal contamination – avian source
CMB140361	Bethells (Waitakere River), 31/12/2013	610	very strong positive	ND	ND	ND	present – up to 10%	ND	present	ND	Faecal contamination – ruminant & avian sources
CMB140372	Bethells (Waitakere River), 27/01/2014	1300	very strong positive	ND	ND	ND	present 10 - 50%	ND	present	ND	Faecal contamination – ruminant & avian sources
CMB140455	Bethells Waitakere River, 10/02/2014	1600	very strong positive	ND	ND	ND	present – 100%	ND	present	ND	Faecal contamination – ruminant & avian sources
CMB140454	Bethells Lagoon, 27/01/2014	1300	very strong positive	ND	ND	ND	present – 50%	present	ND	ND	Faecal contamination – ruminant & dog sources
CMB140377	Bethells Lagoon, 17/02/2014	2500	very strong positive	ND	ND	ND	present up to 1%	present	ND	ND	Faecal contamination – ruminant & dog sources
CMB140379	Bethells Lagoon, 19/02/2014	1400	very strong positive	ND	ND	ND	present up to 1%	present	present	ND	Faecal contamination – ruminant, dog & avian sources
CMB140390	Bethells Lagoon, 5/03/2014	1600	very strong positive	ND	ND	ND	ND	present	present	ND	Faecal contamination – dog & avian sources
CMB140369	Bethells Surf Club, 20/01/2014	590	very strong positive	ND	ND	ND	present – 50%	ND	present	ND	Faecal contamination – ruminant & avian sources
CMB140345	Karekare Stream, 17/12/2013	870	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140348	Karekare Stream, 23/12/2013	810	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140352	Karekare Stream, 30/12/2013	1000	strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140349	Karekare Lagoon, 30/12/2013	1500	very strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140350	Karekare carpark, 30/12/2013	1400	strong positive	ND	ND	ND	ND	ND	ND	ND	Unidentified faecal source
CMB140351	Karekare (Kauri Rd Bridge), 30/12/2013	1400	very strong positive	present	present	ND	ND	ND	ND	ND	Faecal contamination – human source

Abbreviations: ND = sample was analysed, but the determinant was not detected.

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PCR Marker Interpretation Guidance Notes:

General marker

- The general PCR marker was detected in all samples.
- In samples where it was detected at very strong or strong levels we would expect source specific markers to be detected if the contamination was a recent event.
- Where the general marker was detected more weakly - this suggests a more diluted or aged source and thus source specific markers would be less likely to be detected.

Human markers

- Where human markers were detected they were not at "high levels".
- These markers occur at variable levels in human sewage. Thus detecting them at lower levels may still represent a dominant source of pollution.
- Where human indicative markers was either detected in both BacH and BiADO assays or not detected in all assays this gives a higher level of confidence to conclude that a human source is present / not present.
- The HumM3 human marker was not detected in any samples. This reflects that it is a less sensitive marker than either BacH or BiADO

Ruminant marker

- Where ruminant marker was detected, the percentage values given are based on levels of this marker relative to the general marker in fresh ruminant faeces.
- Samples reported as 100% and 50% ruminant are consistent with all of the general faecal marker having come from a ruminant source.
- The lower levels reported (up to 50%, up to 10% and up to 1%) may be a consequence of the presence of other sources of pollution, or in fact ruminant sources may still account for all the pollution, but this may include aged faecal material where relative levels of the ruminant marker decline more rapidly than the general marker.

Dog Marker

We have seen some cross reaction in this assay from human effluent samples but not from individual human faecal samples. This may indication that dog faecal material was present in the effluent samples we tested. In our view, septic tank and urban effluent cannot be presumed to be solely from human sources. When assessing the significance of the dog marker results for these samples consider the likelihood of dogs being present near the sampling area as well as the potential for any human contamination to be from a mixed source.

Bird Marker

The avian specific marker GFD detects duck, swan, seagull, geese and chicken faecal sources

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Notes:

PCR Markers: Each marker is strongly associated with, but not exclusive to the source tested for. They each have some degree of non-specificity. The detection limit of these methods is 1.00E+03, or $1.00x10^3$.

Brief details of the methods of analysis are available on request.
These results relate to samples as received.
This report may not be reproduced except in full.

Paula Scholes	Beth Robson	Susan Lin
Laboratory Manager	Senior Technician	Scientist

Appendix F Piha Domain wastewater system

Piha Domain Wastewater Treatment Plant Discharge Quality				
Date	**BOD (mg/L)**	**TSS (mg/L)**	**Ammonia (mg/L)**	***E. coli* (MPN/100mL)**
21/11/2012	1	1	3.2	<1
20/12/2012	1	2	6.6	<1
27/12/2012	1	1	5.8	<1
3/01/2013	1	1	30	<1
16/01/2013	1	3	4.2	<1
24/01/2013	1	<1	0.72	<1
31/01/2013	2	<1	0.39	<1
5/12/2013	<1	<1	<0.4	<1
11/12/2013	<1	1	<0.4	<1
19/12/2013	1	<1	0.84	<1
27/12/2013	1	2	5.2	<1
2/01/2014	2	1	16	<1
16/01/2014	1	<1	2.7	<1
22/01/2014	<1	1	2.3	<1
30/01/2014	<1	<1	1.6	<1
13/02/2014	1	<1	<0.4	<1
20/02/2014	<1	<1	<0.4	<1
27/02/2014	<1	<1	0.38	<1
6/03/2014	<1	<1	<0.4	140

Find out more: phone 09 301 0101
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