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The Effects of Water Supply Intakes on Macroinvertebrate Communities in the Waikato Region

Weir structure at Oturu Stream (Tairua)

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Executive Summary

1. To assess the influence of water supply intakes on instream habitat and invertebrate communities, we sampled sites upstream and downstream of existing water abstractions on ten Waikato Region streams.

2. Streams were sampled in early summer (December 2006) and again at the end of summer (March 2007) following the time of highest water usage, over the summer holiday period.

3. Sites downstream of water takes generally had lower water velocity, depth and wetted width than upstream sites at the time of sampling, but this varied considerably among streams.

4. Decreases in flow had no effect on water temperature, measured continuously over the low flow period, or on spot measurements of conductivity, pH or dissolved oxygen (DO). There was no overall consistent response of chlorophyll *a* concentrations to water abstraction in either December or March, but variable differences between upstream and downstream sites in individual streams.

5. Despite decreases in velocity, depth and wetted width for most streams, the invertebrate communities at sites upstream and downstream of water intakes remained similar in terms of community composition, invertebrate density, number of taxa, and the percentages of Ephemeroptera, Plecoptera and Trichoptera (EPT) individuals and taxa (excluding Hydroptilidae).

6. A comparison of invertebrate communities in December 2006 and March 2007 showed that the high water take period could increase the influence of water abstractions on invertebrate communities in some streams.

7. The downstream site at Waitete Stream appeared to be the most impacted by water abstraction. There was visibly more sediment accumulation and more algae at the downstream site on this stream and the invertebrate communities at sites upstream and downstream of the water intake were the most dissimilar of all streams in the study both before and after the main water take period. The small size of this stream and the high proportion of flow removed might make this stream more vulnerable to water abstraction than the larger streams in this study.

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1 Introduction

Water abstractions can cause substantial alterations to the natural flow regime (Poff *et al.* 1997). Water removal can result in numerous changes to the instream environment and physical habitat, such as reduced wetted width, decreased water velocities, and decreased depths (Dewson et al. in press). These hydrological changes might result in negative consequences for aquatic life and water quality (Jackson et al. 2001). Changes to nutrient concentrations (Ladle & Bass 1981, Rader & Belish 1999), increased water temperatures (Everard 1996, Rader & Belish 1999) and lowered dissolved oxygen levels (Everard 1996, Jowett 1997) can also result from reduced discharge and these changes could further influence the invertebrate community. Consequently, flow reduction might initiate changes to the invertebrate community by altering the characteristics and availability of instream habitat for invertebrates (Statzner & Higler 1986, Hart & Finelli 1999).

Changes to invertebrate community abundance, diversity or composition could indicate that water takes are having an impact on the stream ecosystem. Reduced flows can result in reduced taxonomic richness if habitat diversity decreases with decreasing discharge (e.g., Cazoubon & Giudicelli 1999, McIntosh et al. 2002), or if there are changes in the condition of the habitat (Wood & Armitage 1999, Wood et al. 2000). Invertebrate densities may respond either positively or negatively to reduced discharge (e.g., Englund & Malmqvist 1996, McIntosh et al. 2002, Dewson et al. in press), and some studies have noted that invertebrate responses to water abstractions vary between streams (Castella et al. 1995, Rader & Belish 1999, Suren et al. 2003).

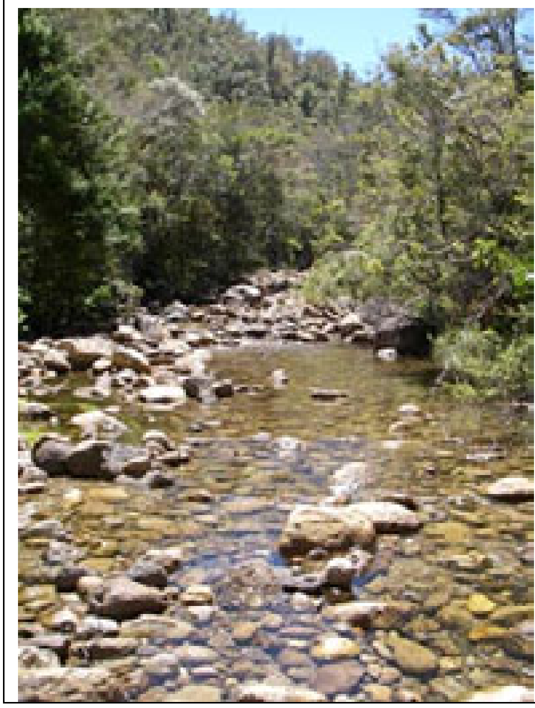
The aim of this study was to assess the influence of water abstractions on the invertebrate communities of ten small permanent streams in the Waikato Region, at sites dominated by native forest cover. We sampled sites upstream and downstream of existing water abstractions, once in early summer and again at the end of summer, to assess the influence of these water takes on stream ecosystems over the high water usage summer period. We hypothesised that downstream of water abstractions, there would be lower water velocity and depth, and decreased wetted channel width compared to upstream. We expected that such changes to flow characteristics would decrease habitat availability and suitability at downstream sites, resulting in lower benthic invertebrate taxonomic richness or density, and lower water quality as measured by invertebrate community metrics.

2 Methods

2.1 Study sites

To assess the influence of water abstractions, we chose pairs of sites, upstream and downstream of water abstractions on ten small streams. The streams were Pepe Stream (Tairua, Plate 1), Oturu Stream (Tairua, Plate 2), Mangarehu Stream (Thames, Plate 3), Matatoki Stream (Waihou, Plate 4), Omahu Stream (Waihou, Plate 5), Waitete Stream (Waihi, Plate 6), Walmsley Stream (Waihi, Plate 7), Mangauika Stream (Pirongia, Plate 8), Pohomihi Stream (Te Aroha, Plate 9) and Pohomihi Stream tributary (Te Aroha, Plate 10). These streams were between 2.5 and 12.0 m wide (total channel width), with average velocities between 0.27 and 0.65 m/s (Table 1). The conductivity of the water in these streams was between 51 and 105 µS/cm, and they were all small, relatively pristine, riffle-pool streams, used for municipal and rural water supply (Appendices 1 & 2). At each site, the channel was partially shaded, with native trees and shrubs in the riparian zone. In each stream, weirs separated upstream and downstream sites and the streams utilised a diversity of water collection structures (Plates 10-13). The daily volume of water abstracted can vary over time (Appendix 3), but unfortunately, water take records were only available for some of the streams used in this study.

Plate 1: Pepe Stream (Tairua), upstream (left) and downstream (right) of the water intake



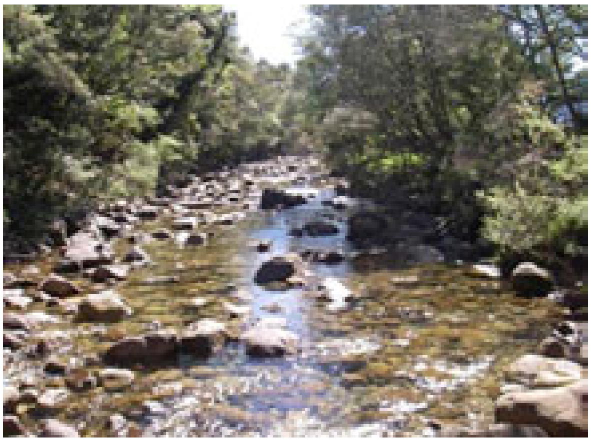


Plate 2: Oturu Stream (Tairua), upstream (left) and downstream (right) of the water intake.

Plate 3: **Mangarehu Stream (Thames), upstream (left) and downstream (right) of the water intake.**

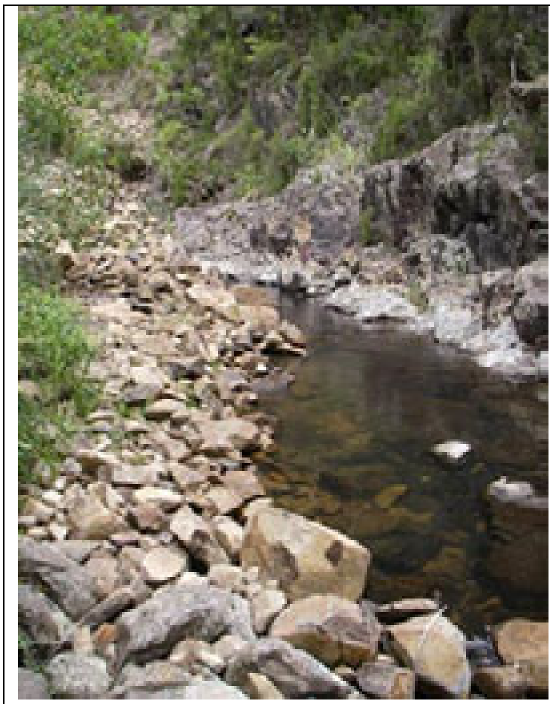


Plate 4: **Matatoki Stream (Waihou), upstream (left) and downstream (right) of the water intake weir.**

Plate 5: **Omahu Stream (Waihou), upstream of the water intake weir.**

Plate 6: **Waitete Stream (Waihi), upstream of the water intake weir.**

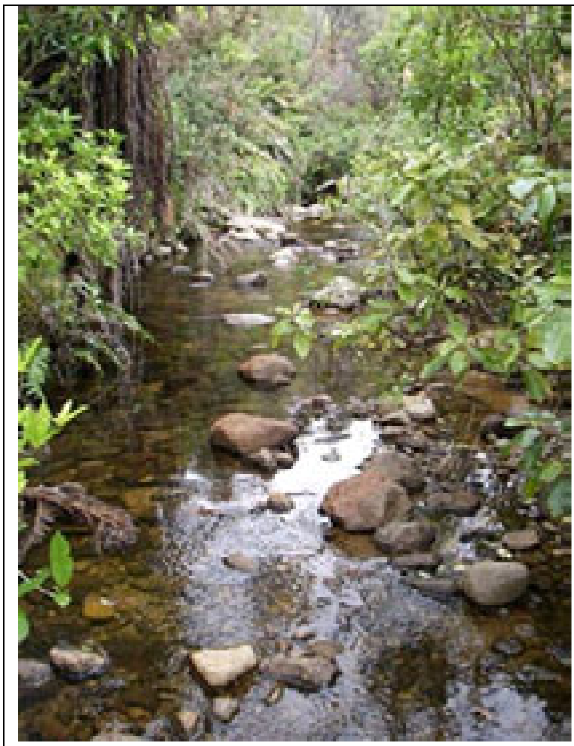


Plate 7: **Walmsley Stream (Waihi), upstream (left) and downstream (right) of the water intake weir.**

Plate 8: **Mangauika Stream (Pirongia), upstream of the water intake weir.**

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Plate 10: Pohomihi Stream tributary (Te Aroha), looking upstream towards water intake structure.

Plate 11: Weir structure at Mangarehu Stream (Thames).

Plate 12: Pepe Stream (Tairua). The water intake structure is marked with a red arrow

Plate 13: Weir structure at Walmsley Stream (Waihi). Photo taken looking upstream.

2.2 Survey design

We sampled each site twice, in early summer (December 2006) and late summer (March 2007) to represent the time before and after the main water take period for these streams. Hydrographs for each site were developed from regressions with nearby flow monitoring sites and are presented as Appendix 4. Samples were collected from riffle habitat, within a 50 m long study reach at each site. Study reaches were generally located within 100 m upstream or downstream of the weir on each stream, however, our priority was to select sites that were outside the direct influence of the weir (e.g., pooling above and below the weir, sharp changes in gradient, bedrock at weir sites). Our sampling focused on riffles, as they were the dominant habitat type in these streams. We expected that this habitat type would be most sensitive to water abstraction, since at very low flows, riffles may dry completely, leaving a series of isolated pools (Gordon et al. 2004).

One drawback of investigating the effects of existing water intakes on the instream environment and invertebrate communities, is that affected sites must necessarily be located downstream of the water removal, with control sites upstream. This complicates the results, since changes unrelated to the water abstraction could also occur between sites. Changes to invertebrate communities between upstream and downstream sites could result from changes in land usage between the sites. To avoid this confounding variable, upstream and downstream sites in this study were located in pristine forested catchments. We also visually selected upstream and downstream sites for their similarity in terms of gradient, substrate size, and proportion of habitat types available (i.e., pool/riffle/run).

2.3 Sampling protocols

Specific conductivity, dissolved oxygen and pH were measured on each occasion using a YSI Incorporated multi-probe system instrument (YSI 556 MPS) (YSI Incorporated, Yellow Springs, OH, U.S.A.). Temperature was recorded at 30 minute intervals between the two samplings (December 2006 to March 2007) using Onset Hobo® H8 temperature loggers (Onset Computer Corporation, Bourne, MA, U.S.A.). We measured the wetted width and total width (to edge of active channel/bank full width) of the channel at 11 locations at 5-m intervals along the 50 m study reach at each sampling, and recorded the habitat type at each cross section (i.e., pool, run, riffle). We used regular intervals for these measurements to get an idea of the loss of wetted width in proportion to the amount of each habitat type in the stream.

We assessed the percentage cover of each substrate size category (bedrock, boulder, cobble, gravel, sand, silt) by measuring and categorising 50 substrate elements, selected using the Wolman walk method (Wolman 1954). A habitat score was also calculated for each site (Collier & Kelly 2005).

At each site, five Surber samples (250 µm mesh, area = 0.1 m^2) were collected within riffle habitat and preserved with 10% formalin until processing. Depth and velocity were measured at each sample location using a Marsh McBirney Inc. Model 2000 Portable Flowmeter (Marsh McBirney Incorporated, Frederick, MD, U.S.A.).

In the laboratory, samples were rinsed through a 500 µm Endecott sieve and invertebrates were sorted and identified using the keys of Winterbourn (1973), Winterbourn et al*.* (2000) and Smith (2003).

We collected one stone (< 60 mm, a-dimension) adjacent to each Surber sample for periphyton biomass analysis. Samples were transported on ice in the dark and stored at minus 20°C until analysis. Photosynthetic pigments were extracted from cobbles by submerging them in 90% acetone for 24 hours at 5°C. Absorbance was read at 750, 665 and 664 nm on a Varian Cary 50 Conc. UV-Visible spectrophotometer™ before and after 0.1M HCl was added. The amount of chlorophyll *a* (µg/cm^2) was calculated for each cobble as described by Steinman & Lamberti (1996) and corrected for stone surface area, calculated using the length, width and depth of each cobble (Graham et al*.* 1988).

We used ice-cream sticks as a measure of organic matter decay rates in these streams. The sticks were dried and weighed before installation. We installed a set of five sticks at upstream and downstream sites on each stream in early December 2006 and collected the sticks in late March 2007. Sticks were installed for between 96 and 106 days, but the number of days exposed was always equal for upstream and downstream sites on the same stream. Upon removal from the stream, sticks were transported on ice, dried and reweighed at Environment Waikato. We then calculated the percentage of the original weight remaining following immersion for each stick.

2.4 Data analysis

One-way analysis of variance (ANOVA) was used to examine differences to water temperature and spot measures of chemical variables between sites upstream and downstream of water intakes using STATISTIX 8 (Analytical Software, Tallahassee, FL). Each stream was a replicate in this analysis.

We calculated invertebrate density, number of taxa, the percentage of Ephemeroptera, Plecoptera and Trichoptera (% EPT) individuals and taxa (Lenat 1988), excluding

Hydroptilidae (Boothroyd & Stark 2000), Macroinvertebrate Community Index (MCI) (Stark 1985) and the Quantitative Macroinvertebrate Community Index (QMCI) (Stark 1985) for each sample to describe the invertebrate communities. Two-way analysis of variance (ANOVA) was used to examine differences in these invertebrate community indices and to determine the chlorophyll *a* concentrations of periphyton between sites upstream and downstream of water intakes on each stream using STATISTIX 8. In this before-after (BA), control-impact (CI) design, treatment factors were sampling occasion (before and after the high water use period of summer) and upstream/downstream of abstraction (control-impact). In this case, both the control-impact (CI) and BA×CI interaction terms in this model can be used as tests for the impact of flow reduction. All factors were treated as fixed effects, since sites and times were chosen, not a random selection of all possible options. We used the five samples taken from each site as replicates for this analysis.

We calculated the average abundance of each invertebrate taxon on each sampling occasion for upstream and downstream sites on each of the ten streams. This data was fourth root transformed to reduce the importance of abundant taxa. Non-metric multi-dimensional scaling (MDS) was carried out using the Bray Curtis similarity measure and we used analysis of similarities (ANOSIM) to test the differences between upstream and downstream groups on each sampling occasion for all streams using PRIMER (Clarke & Gorley 2006).

3 Results

3.1 Physicochemical characteristics

Mean water velocities decreased downstream in all streams except Walmsley and Oturu (Table 1). Mean water depths and wetted widths were also lower at downstream sites on most streams (Table 1). The percentage decreases in velocity, depth and wetted width between upstream and downstream sites varied considerably among the ten streams. Six of the ten sites downstream of water intakes had water velocities and depths that were over 10% lower than upstream sites, and only four of the streams showed any increase in velocity, depth or wetted width between upstream and downstream sites (Table 1). All streams retained flowing water habitats at the time of sampling, with mean velocities ranging from 0.15 m/s to 0.58 m/s at downstream sites, compared to a range of 0.27 m/s to 0.65 m/s at sites upstream of water intakes (Table 1).

There were no differences to spot measures of conductivity ($F_{1,\ 18}$ = 0.43, p = 0.52), dissolved oxygen ($F_{1,\ 18}$ = 0.69, p = 0.42) or pH ($F_{1,\ 18}$ = 0.07, p = 0.80) between upstream and downstream sites on these streams on visits before or after the main water take period. Temperature records for the period between December 2006 and March 2007 showed that mean water temperature was on average <0.5°C higher at downstream than upstream sites, but this difference was not significant ($F_{1,\ 16}$ = 0.09, p = 0.76) (Appendix 5). Neither were there any significant differences in the maximum daily ($F_{1,\ 16}$ = 0.01, p = 0.93) or minimum daily ($F_{1,\ 16}$ = 0.18, p = 0.67) temperatures between upstream and downstream sites on these streams.

Table 1: Mean velocity (n = 10), depth (n = 10) and wetted width (n = 22) at sites upstream and downstream of water intakes in ten streams in the Waikato Region in December 2006 and March 2007. Percentage changes in these variables from upstream to downstream sites are shown in red (decreases) and blue (increase or no change).

Stream	Upstream velocity (m/s)	Downstream velocity (m/s)	% change in velocity	Upstream depth (m)	Downstream depth (m)	% change in depth	Upstream wet width (m)	Downstream wet width (m)	% change in wet width
Waitete	0.47 ± 0.07	0.15 ± 0.04	-68.1	12.4 ± 1.1	8.4 ± 1.2	-32.3	2.1 ± 0.1	2.1 ± 0.2	0.0
Pohomihi	0.51 ± 0.05	0.35 ± 0.05	-31.4	17.4 ± 1.2	9.7 ± 1.0	-44.3	5.5 ± 0.4	4.0 ± 0.4	-27.3
Pohomihi trib.	0.49 ± 0.04	0.28 ± 0.03	-42.9	8.5 ± 0.6	6.7 ± 0.7	-21.2	1.9 ± 0.1	1.3 ± 0.1	-31.6
Mangarehu	0.35 ± 0.05	0.22 ± 0.02	-37.1	20.7 ± 1.7	11.5 ± 1.1	-44.4	4.0 ± 0.3	4.0 ± 0.4	0.0
Mangauika	0.65 ± 0.07	0.58 ± 0.08	-10.8	21.7 ± 1.3	19.5 ± 2.6	-10.1	7.3 ± 0.3	5.2 ± 0.3	-28.8
Omahu	0.64 ± 0.06	0.47 ± 0.04	-26.6	13.0 ± 0.7	15.5 ± 0.9	+19.2	8.1 ± 0.4	4.4 ± 0.2	-45.0
Pepe	0.44 ± 0.06	0.38 ± 0.05	-13.6	11.9 ± 1.1	15.3 ± 1.1	+28.6	8.0 ± 0.4	5.7 ± 0.2	-28.8
Matatoki	0.38 ± 0.06	0.31 ± 0.05	-18.4	10.8 ± 0.9	9.6 ± 1.1	-11.1	3.3 ± 0.3	3.3 ± 0.2	-3.0
Walmsley	0.27 ± 0.04	0.29 ± 0.04	+7.4	13.3 ± 1.5	11.6 ± 0.8	-12.8	3.4 ± 0.1	4.0 ± 0.2	+17.6
Oturu	0.39 ± 0.06	0.47 ± 0.07	+20.5	13.9 ± 1.4	21.1 ± 1.7	+51.8	8.9 ± 0.3	6.6 ± 0.2	-25.8

3.2 Periphyton biomass

Mean chlorophyll *a* concentrations did not consistently increase or decrease downstream of water intakes compared to upstream sites in these ten streams (Table 2, Fig. 1). Several streams had higher concentrations of chlorophyll *a* at downstream sites, whereas others had higher chlorophyll *a* at upstream sites (Fig. 1), although these changes were not significant. The chlorophyll *a* concentration of periphyton in Omahu, Pepe and Walmsley streams increased significantly between the December and March samplings (Appendix 6), but this increase was evident for both upstream and downstream sites on these streams.

Table 2: Mean chlorophyll *a* concentration of periphyton on cobbles (n = 5) collected from sites upstream and downstream of water intakes on ten streams in the Waikato Region in December 2006 and March 2007.

	December		**March**	
	Upstream ($\mu g/cm^2$)	**Downstream ($\mu g/cm^2$)**	**Upstream ($\mu g/cm^2$)**	**Downstream ($\mu g/cm^2$)**
Waitete	2.69	3.79	2.38	6.29
Pohomihi	1.33	1.41	1.81	1.27
Pohomihi trib.	4.71	2.76	3.74	2.23
Mangarehu	0.63	0.69	0.56	0.94
Mangauika	1.42	1.32	1.67	0.93
Omahu	3.21	3.23	15.66	7.83
Pepe	2.67	1.35	3.91	3.11
Matatoki	2.10	5.05	3.01	5.83
Walmsley	1.55	1.54	3.45	3.40
Oturu	1.24	2.10	2.15	4.18
Mean ± 1 S.E.	2.15 ± 0.36	1.84 ± 0.41	2.50 ± 1.29	2.60 ± 0.73

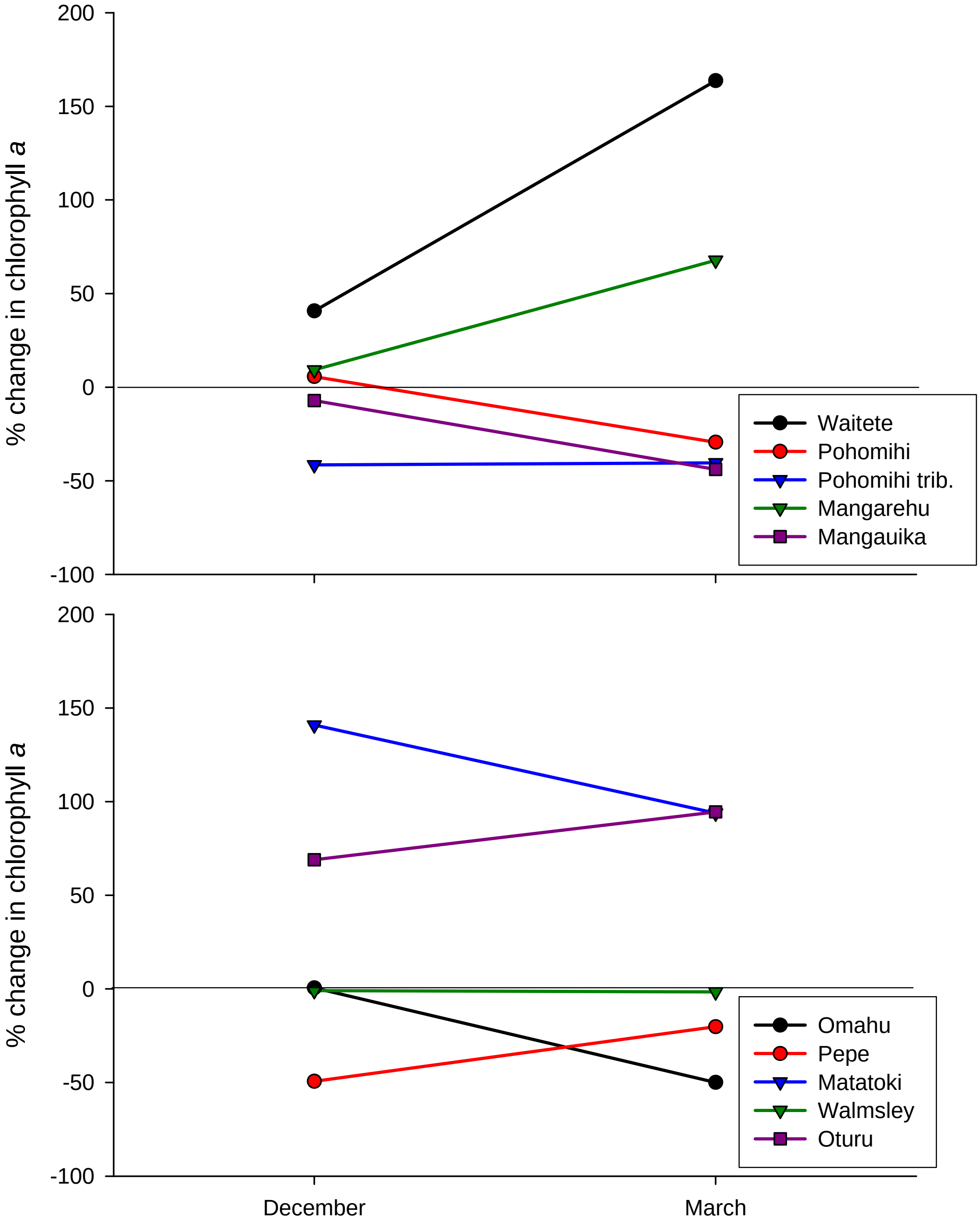

Figure 1: **Percent change in the chlorophyll a concentration of periphyton on cobbles between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that the concentration of chlorophyll *a* decreased downstream of the water intake and positive percent change values indicate that the concentration of chlorophyll *a* increased downstream of the water intake.**

3.3 Decomposition

There was no consistent increase or decrease in stick decomposition between upstream and downstream sites on these streams (Fig. 2). However, there was greater stick decomposition at upstream than downstream sites on five streams (Waitete, Pohomihi, Pohomihi trib., Omahu, Walmsley), and no visible difference between upstream and downstream on three further streams (Mangarehu, Mangauika, Matatoki). Sticks gained weight at either upstream or downstream sites on Waitete, Mangarehu, Walmsley and Oturu streams (Fig. 2).

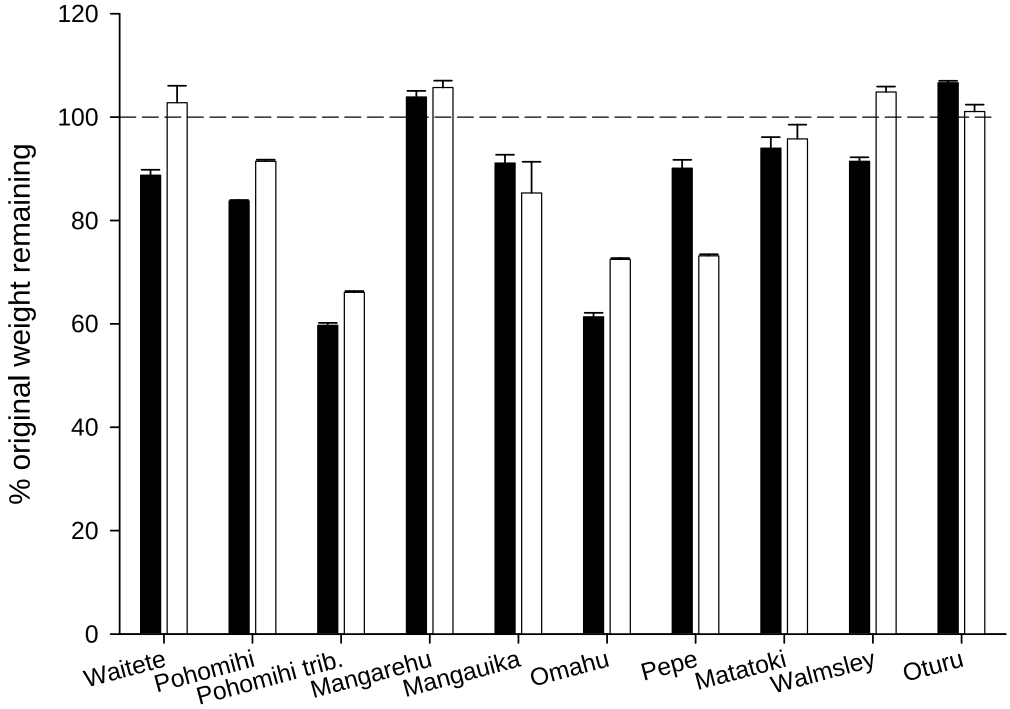

Figure 2: Percentage of the original dry weight remaining for sticks installed at sites upstream (black bars) and downstream (open bars) of water intakes in ten Waikato Region streams between December 2006 and March 2007. The horizontal dashed line represents the original dry weight (100%) of the sticks.

3.4 Invertebrate community diversity

Invertebrate densities were higher at the downstream site in Omahu Stream, especially at the March sampling (Fig. 3, Appendices 6 & 7). A similar pattern was observed for Oturu Stream, but invertebrate densities did not significantly differ between sites upstream and downstream of water intakes on any of the other streams. Waitete was the only stream where the number of taxa was significantly lower at the downstream site (Fig. 4). The number of taxa per sample was otherwise similar at upstream and downstream sites in both December and March (Fig. 4). The percentage of EPT individuals (Fig. 5) and EPT taxa (Fig. 6) decreased markedly at downstream sites on Waitete and Matatoki streams, while only the percentage of EPT taxa decreased downstream for Oturu Stream. The only substantial decreases to MCI (Fig. 7) and QMCI (Fig. 8) between upstream and downstream sites were observed for Waitete, Matatoki and Oturu streams. There was also a decrease in MCI at the downstream site on Pepe Stream at the time of sampling in March (Appendices 6 & 7).

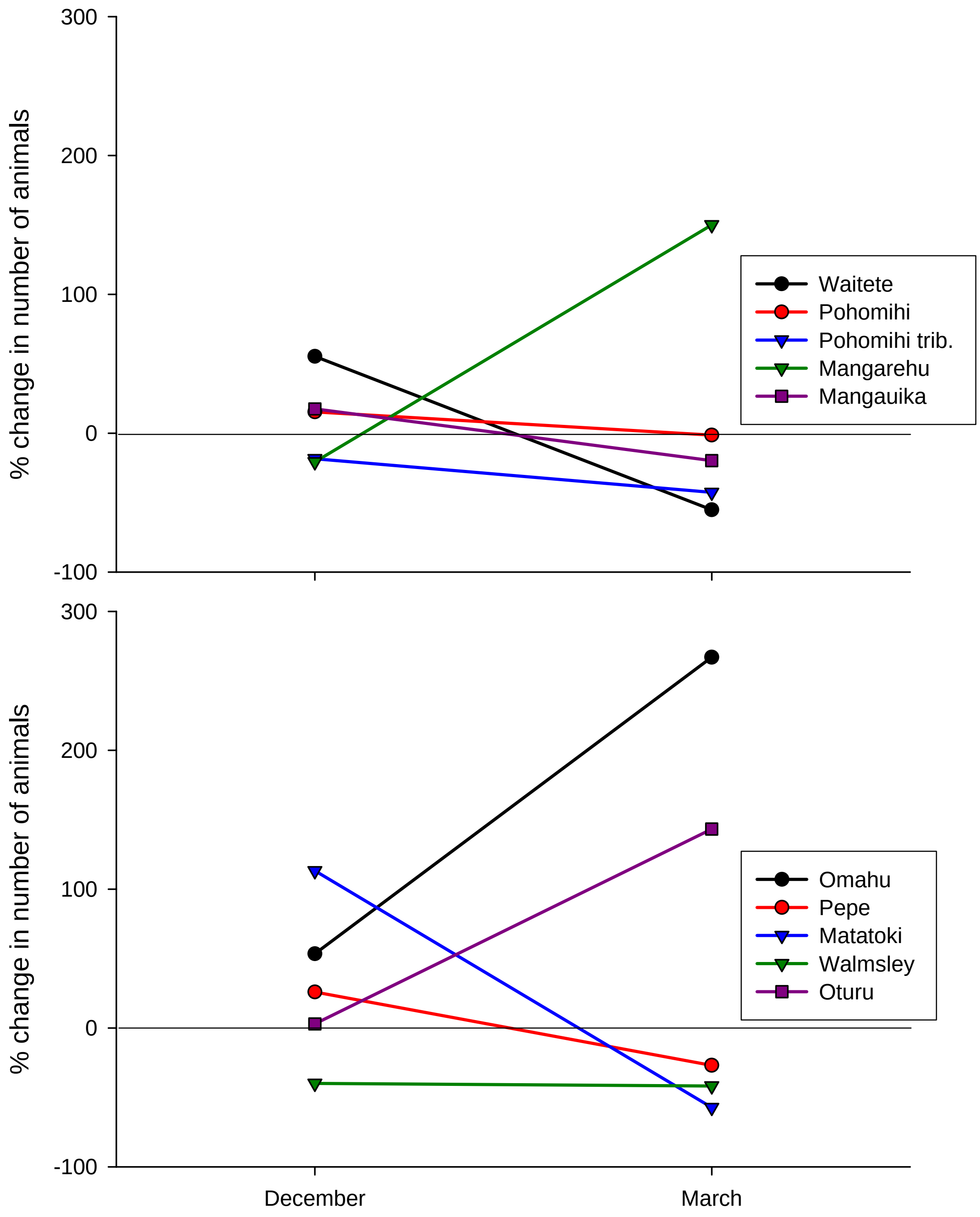

Figure 3: Percent change in the number of animals between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that the number of animals has decreased downstream of the water intake and positive percent change values indicate that the number of animals has increased downstream of the water intake.

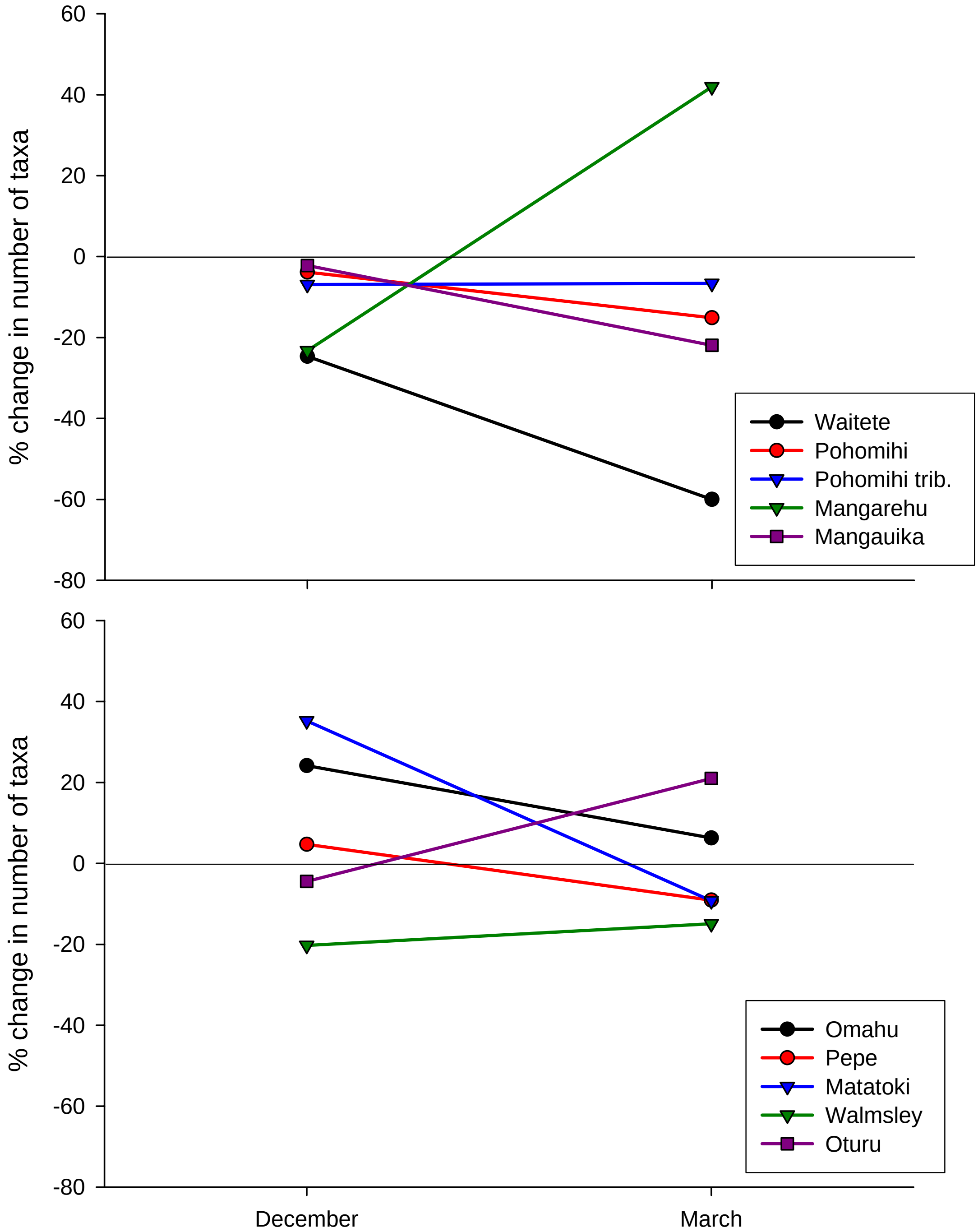

Figure 4:`Percent change in the number of taxa between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that the number of taxa has decreased downstream of the water intake and positive percent change values indicate that the number of taxa has increased downstream of the water intake.

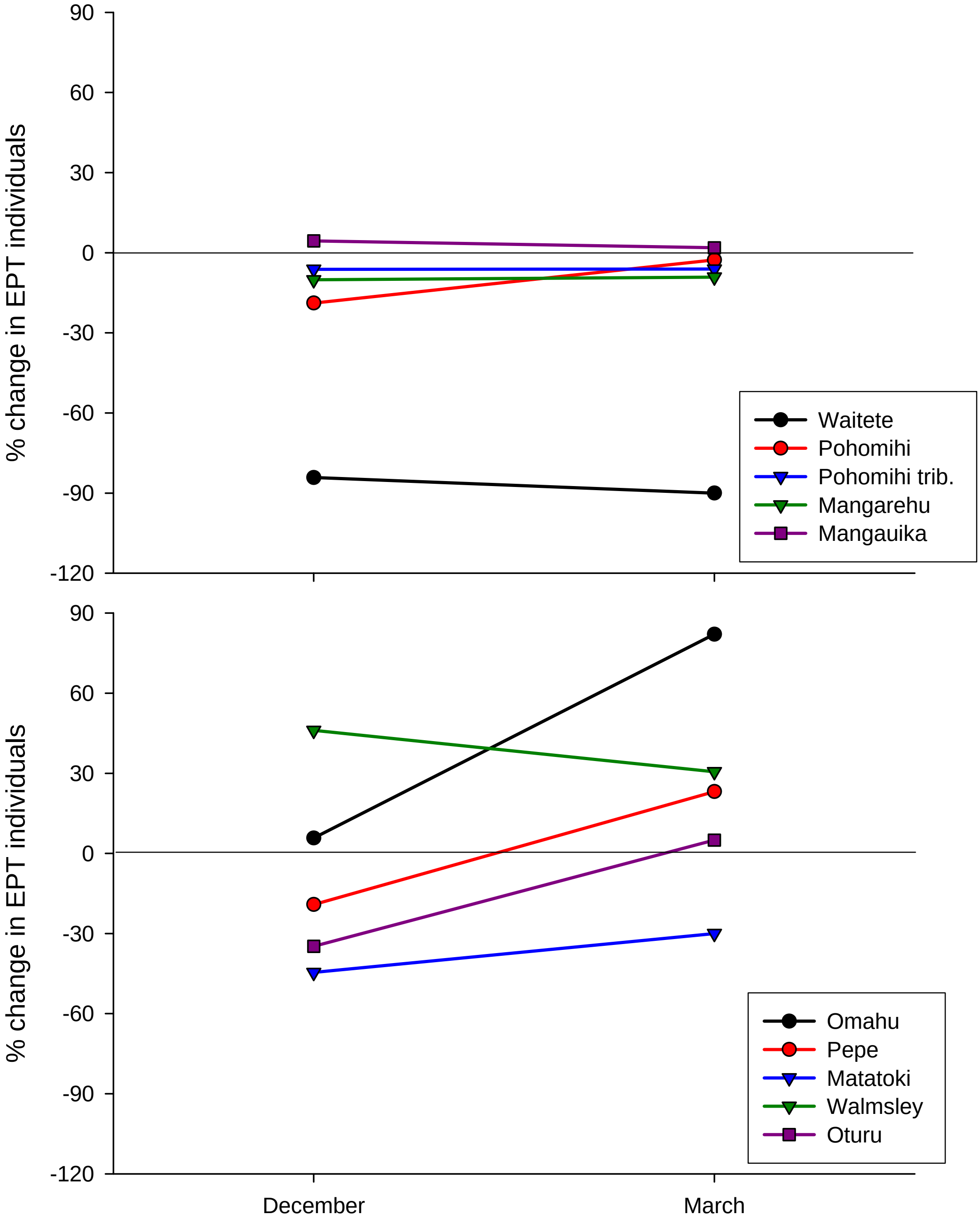

Figure 5: Percent change in the percentage of EPT individuals between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that the percentage of EPT individuals has decreased downstream of the water intake and positive percent change values indicate that the percentage of EPT individuals has increased downstream of the water intake.

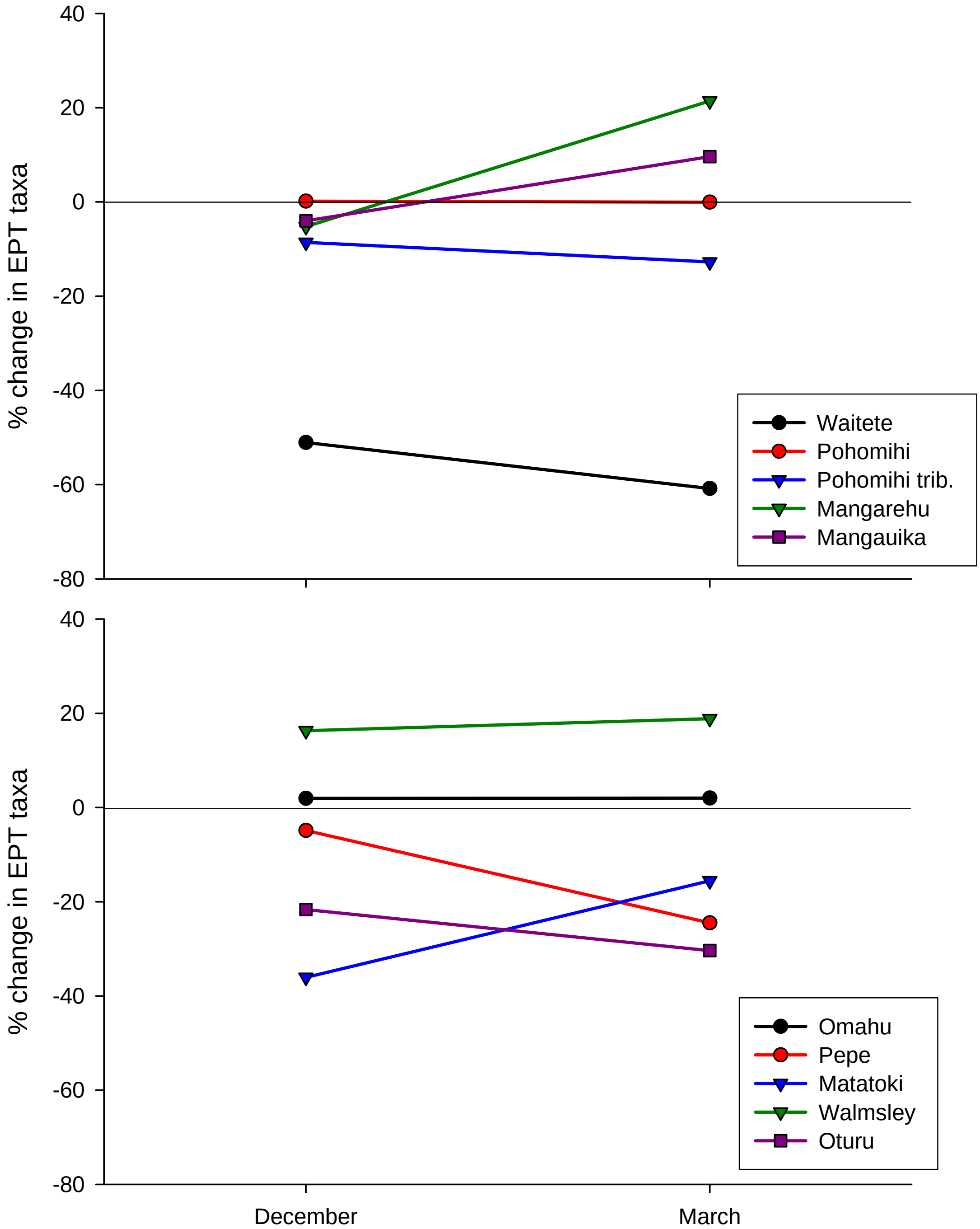

Figure 6: **Percent change in the percentage of EPT taxa between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that the percentage of EPT taxa has decreased downstream of the water intake and positive percent change values indicate that the percentage of EPT taxa has increased downstream of the water intake.**

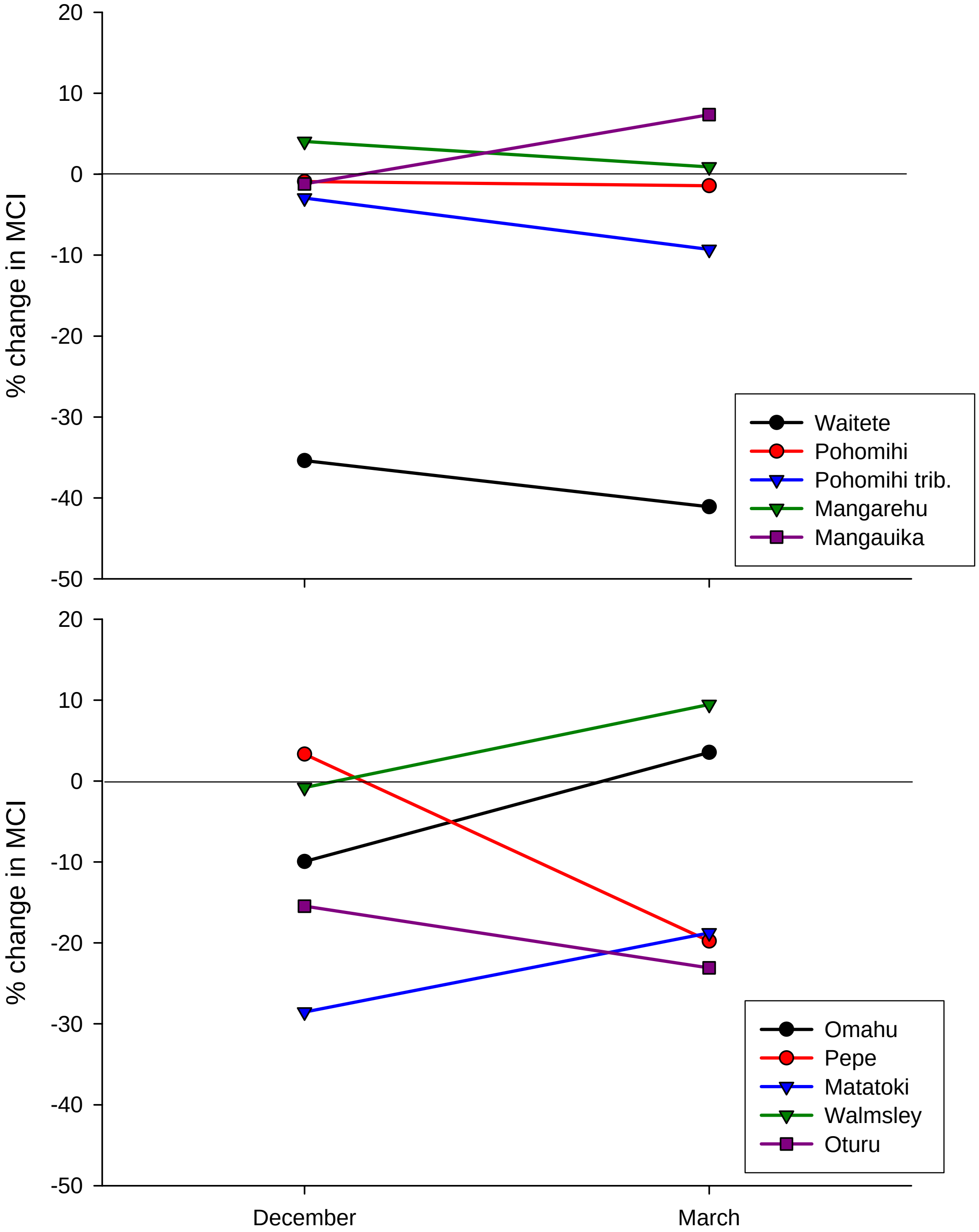

Figure 7: Percent change in MCI between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that the MCI has decreased downstream of the water intake and positive percent change values indicate that the MCI has increased downstream of the water intake.

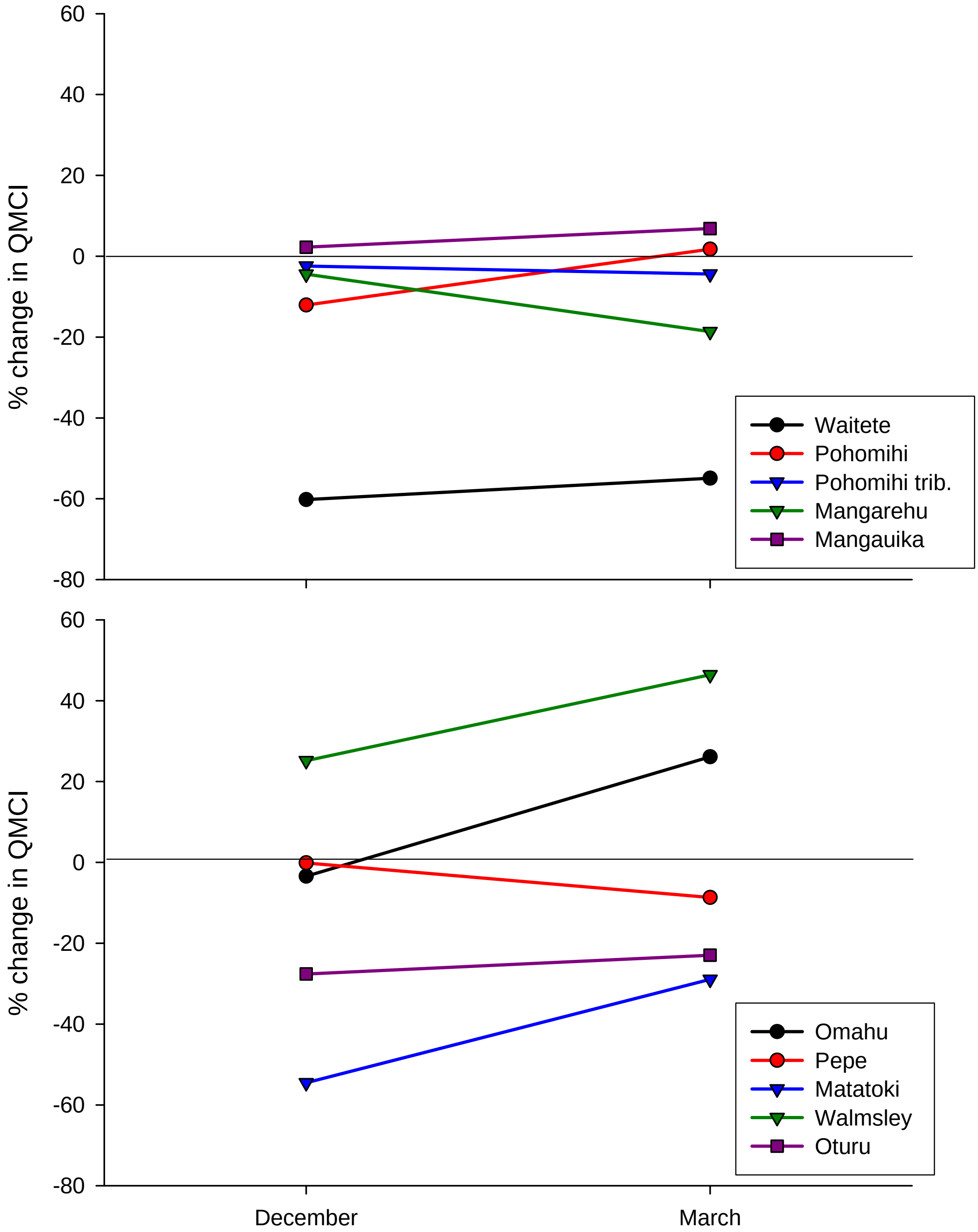

Figure 8: **Percent change in QMCI between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007. Negative percent change values indicate that QMCI has decreased downstream of the water intake and positive percent change values indicate that QMCI has increased downstream of the water intake.**

The changes to invertebrate community indices that are indicative of water quality are summarised in Table 3. Water quality appears to decline at sites downstream of water intakes on Waitete, Matatoki and Oturu streams (Table 3).

Table 3: Summary of changes to invertebrate community metrics between sites upstream and downstream of water intakes in December 2006 and March 2007. Arrows indicate the direction of changes that are significant at the 1% level (see Appendix 6), and - represents no significant change.

Stream	% EPT individuals	% EPT taxa	MCI	QMCI	Overall change
Waitete	⬇	⬇	⬇	⬇	Decline
Pohomihi	-	-	-	-	No change
Pohomihi tributary	-	-	⬇	-	No change
Mangarehu	-	-	-	-	No change
Mangauika	-	-	-	⬆	No change
Omahu	⬆	-	-	-	No change
Pepe	-	-	-	-	No change
Matatoki	⬇	⬇	⬇	⬇	Decline
Walmsley	-	-	-	-	No change
Oturu	-	⬇	⬇	⬇	Decline

3.5 Invertebrate community composition

Sites downstream of water intakes were not significantly different from those upstream over all sites in December (ANOSIM R = -0.02, p = 0.57) (Fig. 9) or March (ANOSIM R = -0.08, p = 0.92) (Fig. 10). Two-way ANOSIM of mean invertebrate communities from the December and March samplings combined showed that there was no difference between upstream and downstream sites over both sampling times (ANOSIM R = -0.05, p = 0.88), or between the communities found in December and March (ANOSIM R = -0.03, p = 0.76) (Fig. 11).

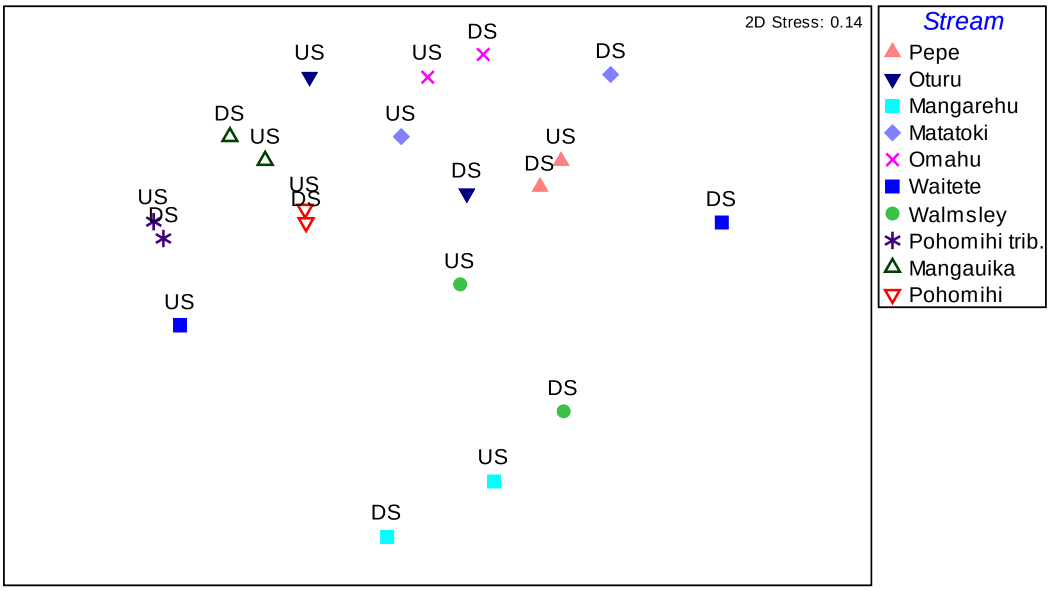

Figure 9: Non-metric multi-dimensional scaling (MDS) of mean (n = 5) invertebrate community collected at sites upstream (US) and downstream (DS) of water intakes in ten Waikato Region streams during December 2006.

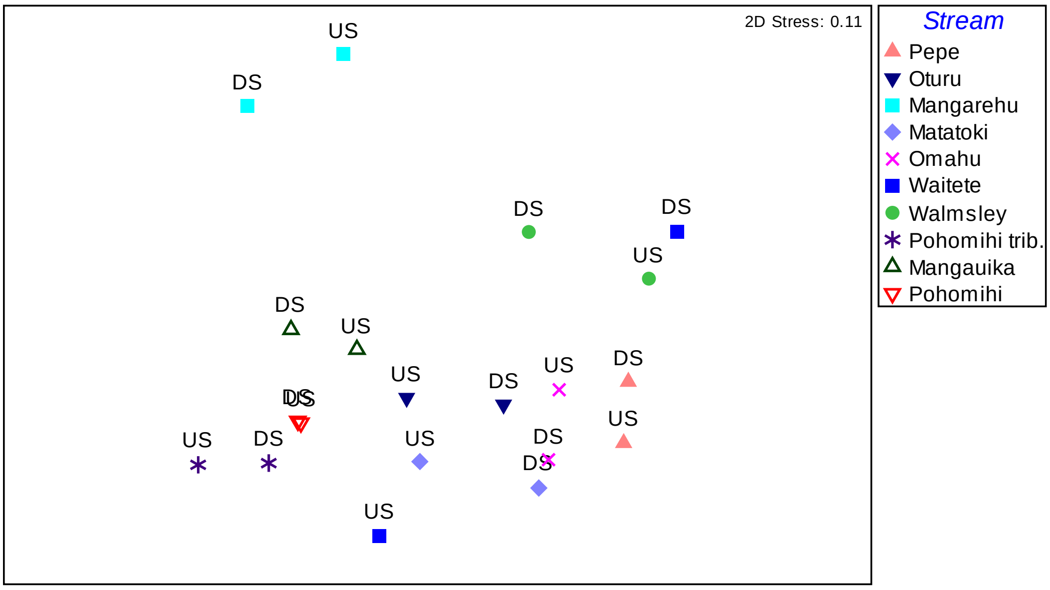

Figure 10: Non-metric multi-dimensional scaling (MDS) of mean (n = 5) invertebrate community collected at sites upstream (US) and downstream (DS) of water intakes in ten Waikato Region streams during March 2007.

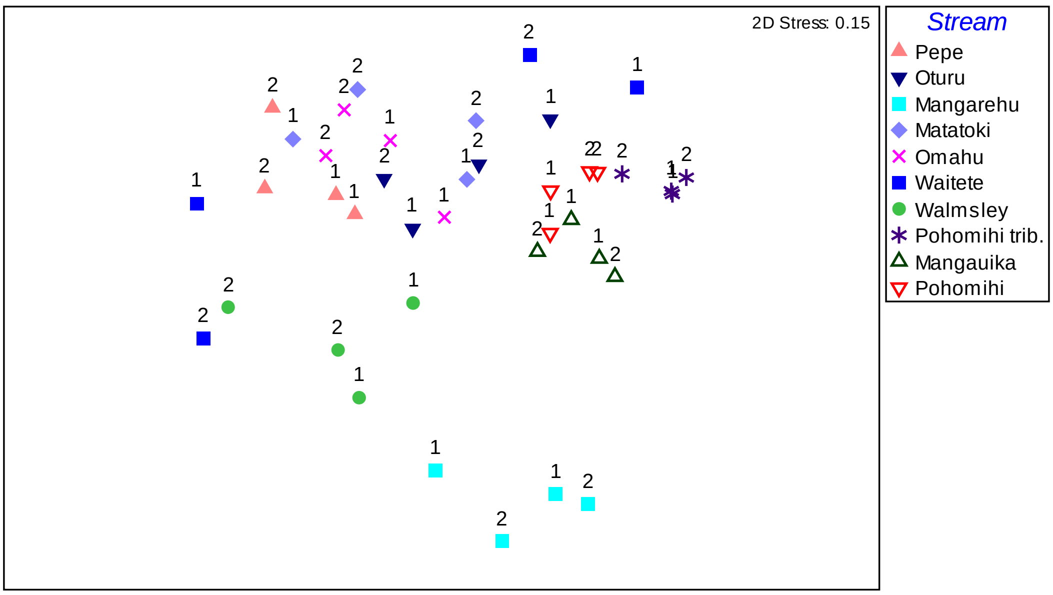

Figure 11: Non-metric multi-dimensional scaling (MDS) of mean (n = 5) invertebrate community collected at sites upstream and downstream of water intakes in ten Waikato Region streams during (1) December 2006 and (2) March 2007.

The greatest difference between the invertebrate community at upstream and downstream sites was on Waitete Stream in both December and March. The greatest similarity between upstream and downstream sites was on the tributary of Pohomihi Stream in December and the Pohomihi mainstream in March (Table 4).

Table 4: Percentage similarity of invertebrate communities at sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and March 2007.

	% similarity between upstream and downstream sites		Increase/decrease in similarity over high water take period
	December	March	
Waitete	42.8	38.5	Decrease
Pohomihi	75.2	86.5	Increase
Pohomihi trib.	80.3	75.8	Decrease
Mangarehu	72.4	59.2	Decrease
Mangauika	80.0	66.7	Decrease
Omahu	76.7	73.1	Decrease
Pepe	78.8	75.6	Decrease
Matatoki	61.6	65.4	Increase
Walmsley	67.6	70.3	Increase
Oturu	59.4	66.8	Increase

4 Conclusions

To assess the influence of water abstractions on the invertebrate communities of ten small permanent streams in the Waikato Region, we compared sites upstream and downstream of existing water abstractions, once in early summer and again at the end of summer. Our sampling was timed to occur before (December) and after (March) the expected time of highest water usage, over the summer holiday period. The water abstractions on these streams were located at sites dominated by native forest cover, to minimise the potentially confounding effects of changing land use between upstream and downstream sites. The results of this study relate to the effects of water takes on these streams over the summer of 2006-2007. We would expect the effects of water abstractions to differ between years, depending on the prevailing weather conditions and the level of water use. Flow in all streams was low for the December sampling, but substantial rainfall during January and early February 2007 interrupted the expected summer low flow period and this may have reduced the effects of water takes on these streams.

Decreases in water velocities, depths and wetted widths occurred downstream of water intakes for the majority of streams in this study. The percentage decreases in these variables between upstream and downstream sites varied considerably among the ten streams. Differences in the proportions of total flow abstracted from each stream probably contributed to this variability, although water take records are not available for all streams to confirm this. However, differences in stream morphology among the streams, and between upstream and downstream sites on individual streams also have an important influence on the observed changes to water velocity, depth and wetted width following water abstraction, because the responses of these variables to changes in discharge depend on the cross-sectional shape of the channel (Gordon et al. 2004).

Although there were substantial downstream percentage decreases in velocity in several streams in this study, riffle habitat was the dominant habitat type at both upstream and downstream sites in most streams. Additionally, the proportion of riffle habitat increased between December and March in most streams, especially at downstream sites (Appendix 1). Our results show that downstream sites are not especially slow flowing in these streams, and with mean velocities of between 0.15 m/s to 0.58 m/s, they may remain suitable for most macroinvertebrates. The lowest mean velocity was recorded downstream of the water intake at Waitete Stream (0.15 m/s). The downstream site at this stream was visually the most altered by water abstraction.

There was visibly more sediment accumulated on the substrate and more algal growth at the downstream site on this stream.

Our spot measures of conductivity, pH and dissolved oxygen did not reveal any consistent changes in response to water removal and neither did our records of water temperature between December 2006 and March 2007. We did observe greater wood decomposition (ice cream sticks) at upstream sites in half of the streams studied, although this did not appear to relate to the severity of flow reduction (as measured by relative decreases in velocity, depth and wetted width). We also observed that while periphyton biomass (as measured by chlorophyll *a* concentration) increased in several of the streams between December 2006 and March 2007, there was no consistent difference in response to water abstraction.

The compositions of the invertebrate communities in most of the streams in this study were unchanged between sites upstream and downstream of water intakes. Although densities of invertebrates per sample were also largely unchanged by flow reductions, the decrease in wetted area (and therefore habitat area) for many of the streams suggests that at the reach scale, invertebrate populations will have decreased in response to the water abstractions.

Of the ten streams in this study, the invertebrate community at Waitete Stream appears to be the most impacted by water abstraction, perhaps because greatest proportion of flow is removed on this stream (although this cannot be confirmed without water take records). Waitete is one of the smallest streams included in this study and this might make it more vulnerable to water abstraction than larger streams.

Water quality also decreased downstream on Matatoki and Oturu streams, but we suggest that water abstraction is not responsible for the changes to invertebrate communities on these streams. At Matatoki Stream, the influence of quarrying activities around the stream, rather than a decrease in flow is probably responsible for invertebrate community changes, since decreases in velocity and depth were relatively minor for this stream. Similarly, for Oturu Stream, it seems unreasonable to attribute invertebrate community changes at the downstream site to water abstraction, since our measurements show that velocity and depth at the downstream site are considerably higher than upstream of the water intake on this stream.

Despite some relatively substantial decreases in velocity, depth and wetted width for the remaining seven streams, the invertebrate communities at upstream and downstream sites remained very similar. This was particularly noticeable for the tributary of Pohomihi Stream and the Pohomihi mainstream, which had the greatest similarity in invertebrate communities between upstream and downstream sites in December and March respectively, even though the relative decreases in velocities, depths and wetted widths in these streams were among the highest in this study.

We anticipated that if water abstractions were having an impact on stream invertebrate communities, the difference between upstream and downstream sites would be greatest for the late summer sampling (March). This sampling followed the higher water usage holiday period, which often coincides with naturally lower stream flows. The BA×CI interaction term in our ANOVA model would detect such effects, by assessing whether changes between before and after at the impact site were similar or different to changes at the control site. Our results showed few significant interactions, suggesting that the high water take period had little influence on the impact of the water takes with a couple of exceptions. At the downstream site on Waitete Stream, the abundance of invertebrates declined relative to upstream, and at the downstream site on Pepe Stream MCI decreased over time relative to upstream. In addition, the similarity of invertebrate community composition between upstream and downstream sites increased between December and March for four streams and decreased over this time for the remaining six streams (Table 4), which were generally those streams with greater decreases in flow variables (as measured by decreases to velocity, depth and width). These changes imply that the impact of water abstraction might increase over the summer period.

In general, the results of this study show that water abstractions are a minor impact on invertebrate communities in these streams. However, the findings at Waitete Stream demonstrate that severe water abstractions can negatively affect invertebrate communities. Potential reasons for the lack of changes to invertebrate communities downstream of water intakes include:

1. low proportions of water abstracted from some of the streams
2. velocities and depths do not get extremely low at downstream sites
3. flowing riffle habitat is maintained at downstream sites
4. little change to habitat quality (e.g., sedimentation, algal biomass, temperature, conductivity)
5. high flow events are relatively frequent

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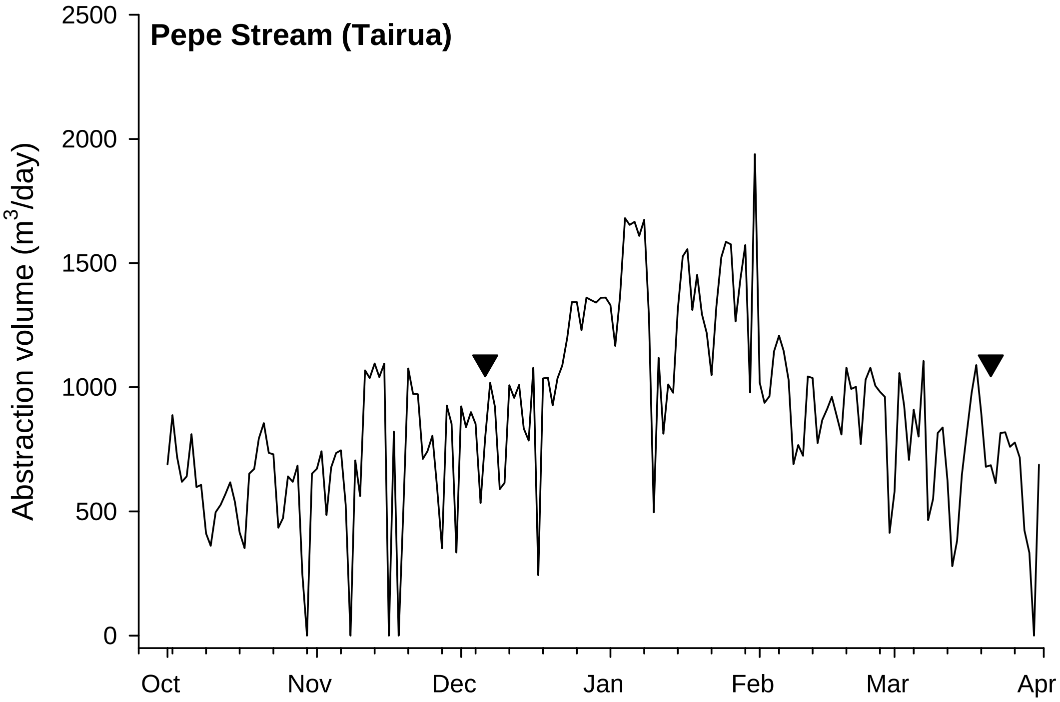
Appendix I: Mean values of chemical and habitat variables recorded at sites upstream and downstream of water intakes on ten Waikato Region streams during December 2006 and March 2007.

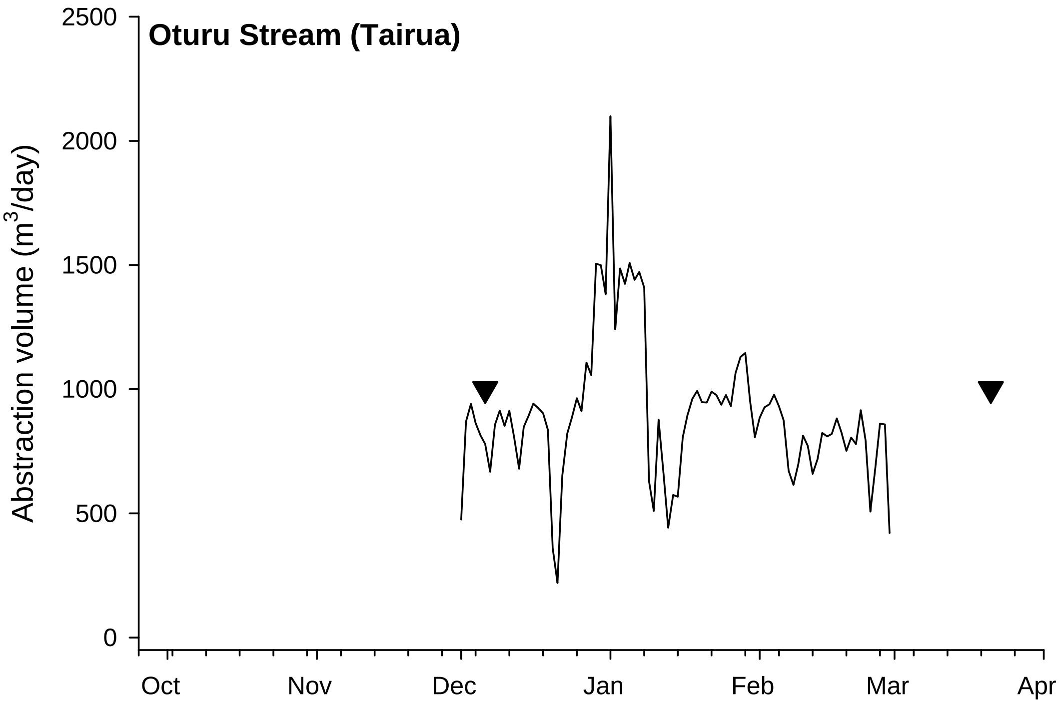
	Chemical			Habitat size								
Stream	**Specific conductivity (µS/cm)**	**Dissolved oxygen (mg/L)**	**pH**	**Stream channel width (m)**	**Wetted width (% of channel)**		**% riffle**		**% run**		**% pool**	
					Dec.	Mar.	Dec	Mar	Dec	Mar	Dec	Mar
Waitete upstream	63	7.8	6.4	2.8	74	78	91	64	0	27	9	9
Waitete downstream	68	11.3	7.9	3.9	55	50	64	73	0	0	36	27
Pohomihi upstream	53	7.7	6.9	6.9	88	72	100	64	0	27	0	9
Pohomihi downstream	67	7.0	6.5	10.4	43	34	80	82	10	0	10	18
Pohomihi trib. upstream	104	7.7	7.1	4.6	41	42	73	73	18	18	9	9
Pohomihi trib. downstream	105	7.4	6.9	2.5	55	47	83	86	0	0	17	14
Mangarehu upstream	98	10.0	6.0	10.6	40	36	64	64	18	27	18	9
Mangarehu downstream	98	9.9	6.1	10.6	41	34	36	64	9	18	55	18
Mangauika upstream	60	7.8	7.4	9.8	71	77	73	73	18	27	9	0
Mangauika downstream	61	9.4	6.6	7.9	59	73	36	82	64	18	0	0
Omahu upstream	57	8.4	6.9	9.3	89	85	55	64	27	9	18	27
Omahu downstream	59	7.9	6.9	9.9	46	42	64	82	18	18	18	0
Pepe upstream	56	7.4	5.9	12.0	71	61	64	55	0	0	36	46
Pepe downstream	56	7.4	6.1	6.6	87	84	91	100	9	0	0	0
Matatoki upstream	65	8.8	7.1	5.9	67	48	64	82	27	18	9	0
Matatoki downstream	96	9.0	6.4	4.7	75	61	73	82	18	18	9	0
Walmsley upstream	51	6.9	6.3	3.8	94	83	64	64	36	36	0	0
Walmsley downstream	53	6.4	6.3	5.4	76	73	55	73	27	9	18	18
Oturu upstream	54	8.4	6.6	10.6	85	84	55	73	46	18	0	9
Oturu downstream	55	9.9	6.3	8.2	83	77	27	73	64	27	9	0

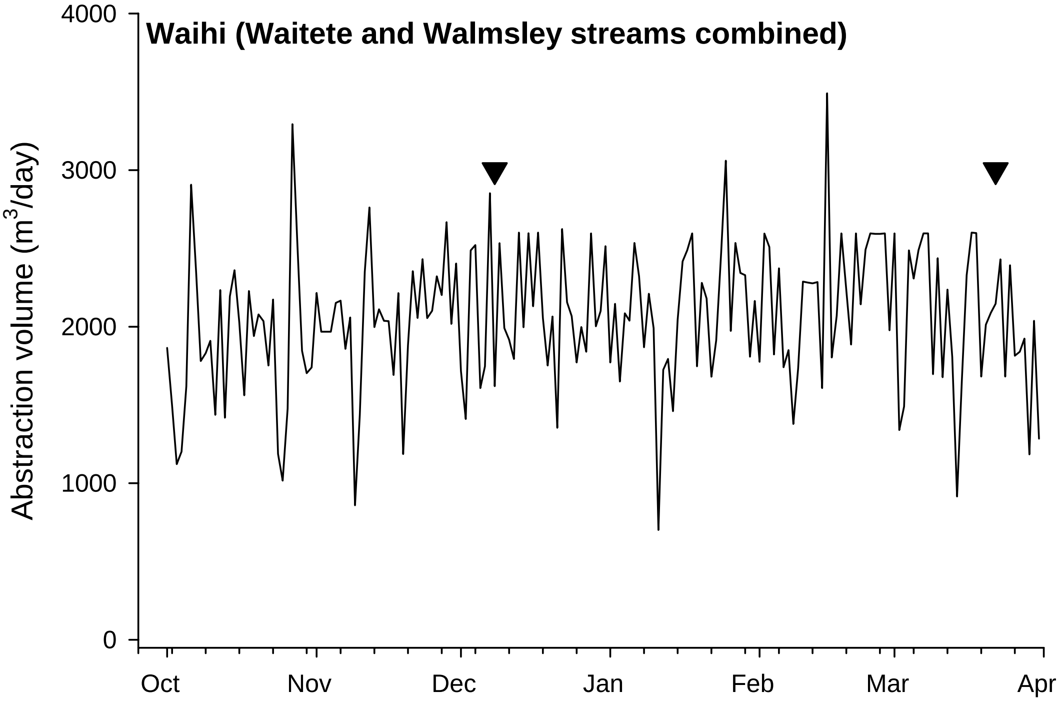
Appendix II: Mean values of the Environment Waikato habitat score (maximum score of 180) (Collier & Kelly 2005), substrate size and the percentage cover of organic matter recorded at sites upstream and downstream of water intakes on ten Waikato Region streams during December 2006 and March 2007.

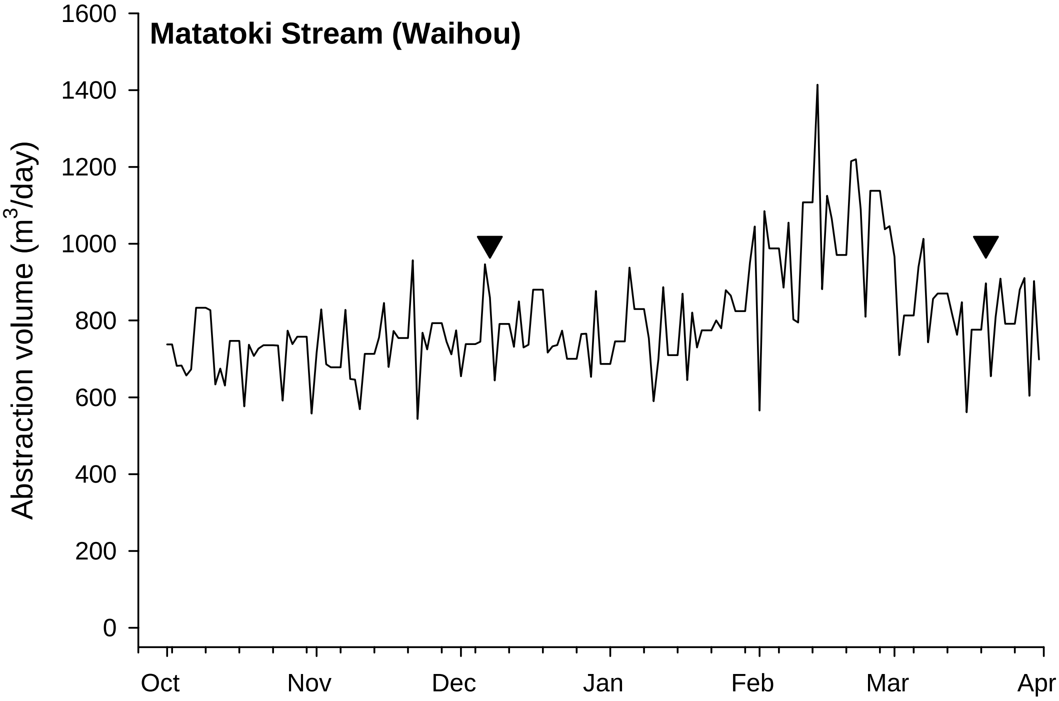
Stream	Habitat score (EW)	Substrate					Organic material cover		
		% bedrock	% boulder (>256 mm)	% cobble (>64-256 mm)	% gravel (>2-64 mm)	% sand (>0.06-2 mm)	% large wood	% coarse detritus	% fine organics
Waitete upstream	159	0	29	42	29	0	5-25	5-25	<5
Waitete downstream	114	2	46	40	10	2	<5	26-50	51-75
Pohomihi upstream	166	0	31	42	23	4	<5	<5	<5
Pohomihi downstream	166	0	25	36	40	0	<5	<5	<5
Pohomihi trib. upstream	168	0	2	28	64	6	<5	5-25	5-25
Pohomihi trib. downstream	161	0	14	24	56	6	<5	5-25	5-25
Mangarehu upstream	167	0	21	50	29	0	<5	<5	5-25
Mangarehu downstream	167	3	14	43	38	2	<5	<5	<5
Mangauika upstream	180	0	30	56	14	0	<5	<5	<5
Mangauika downstream	180	0	26	40	34	0	<5	<5	<5
Omahu upstream	171	0	13	60	24	4	<5	<5	5-25
Omahu downstream	171	0	13	58	27	2	<5	<5	<5
Pepe upstream	163	0	21	52	27	0	<5	5-25	<5
Pepe downstream	166	0	12	37	51	0	<5	5-25	5-25
Matatoki upstream	151	16	25	18	36	5	<5	<5	<5
Matatoki downstream	158	0	20	55	23	2	<5	<5	5-25
Walmsley upstream	164	0	9	58	21	11	<5	5-25	<5
Walmsley downstream	164	0	33	63	19	6	<5	5-25	<5
Oturu upstream	160	0	49	29	22	0	<5	<5	5-25
Oturu downstream	157	0	27	55	16	2	<5	<5	5-25

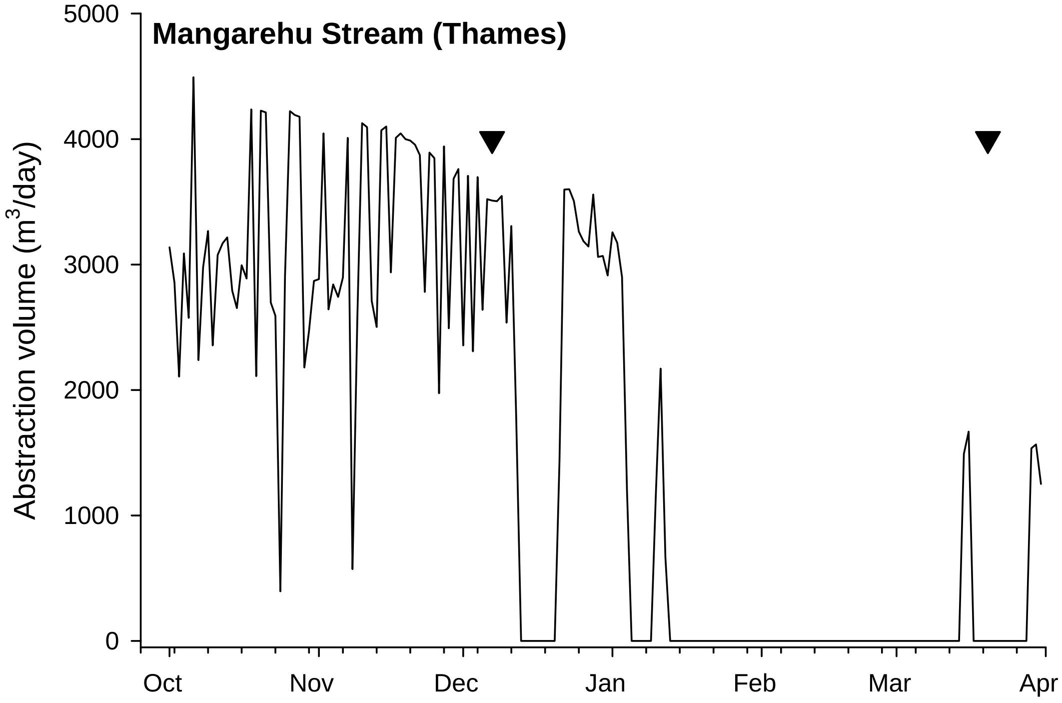
Appendix III: Daily abstraction volumes (m^3/day) for the streams included in this study (where available), for the period between October 2006 and March 2007. Arrows on each graph indicate invertebrate sampling times for each stream.





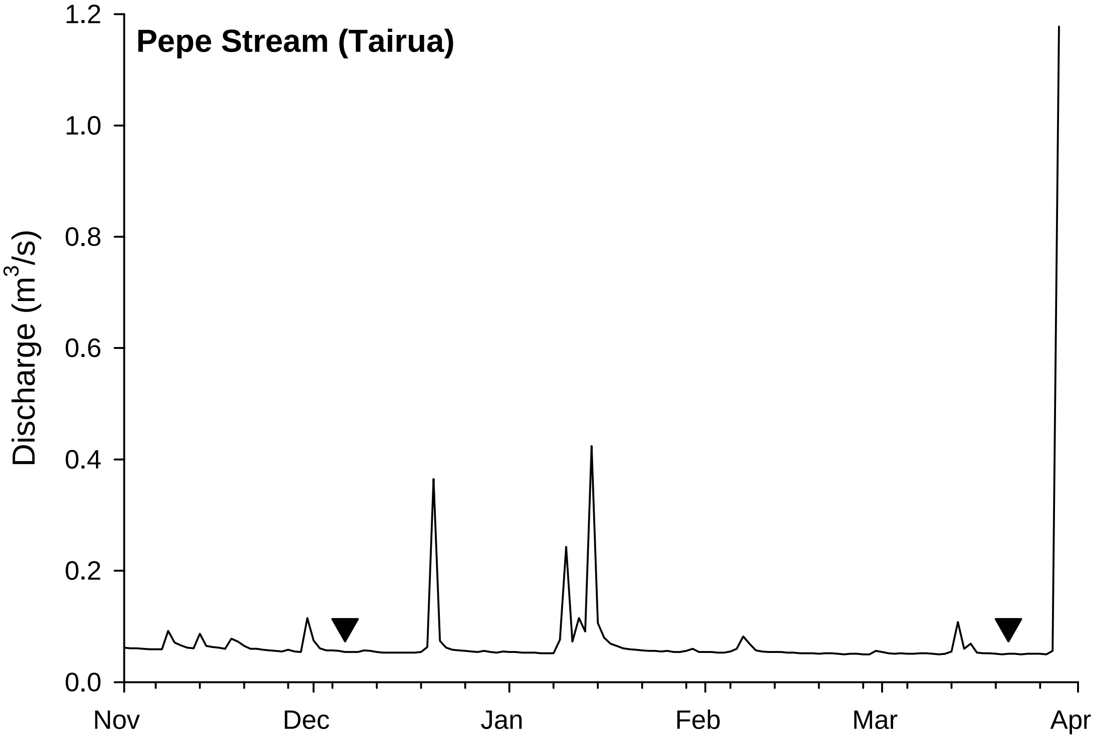

Waihi (Waitete and Walmsley streams combined)
Abstraction volume (m3/day)
4000
3000
2000
1000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr

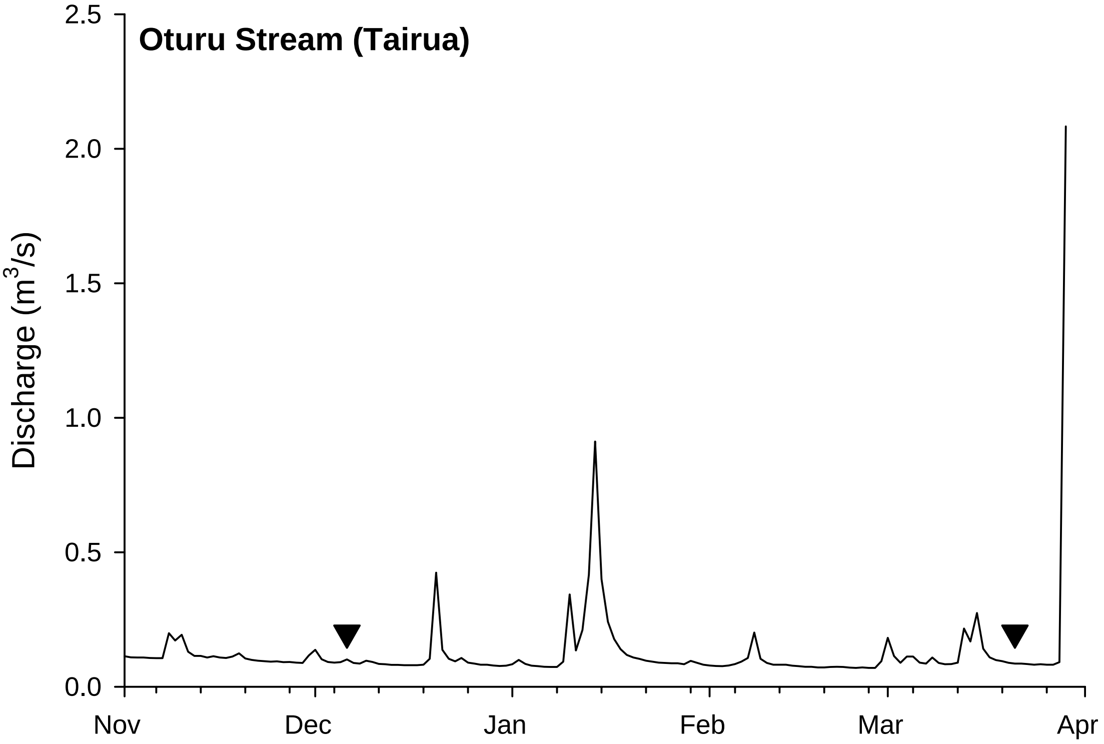

Matatoki Stream (Waihou)
Abstraction volume (m3/day)
1600
1400
1200
1000
800
600
400
200
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr

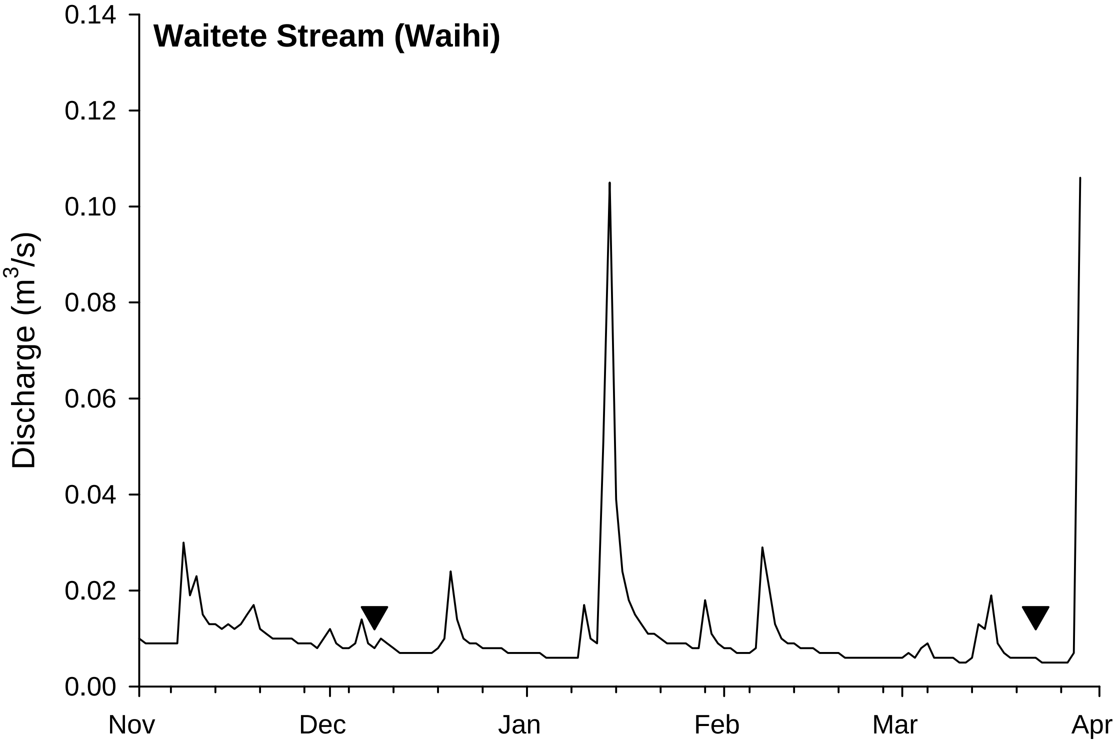


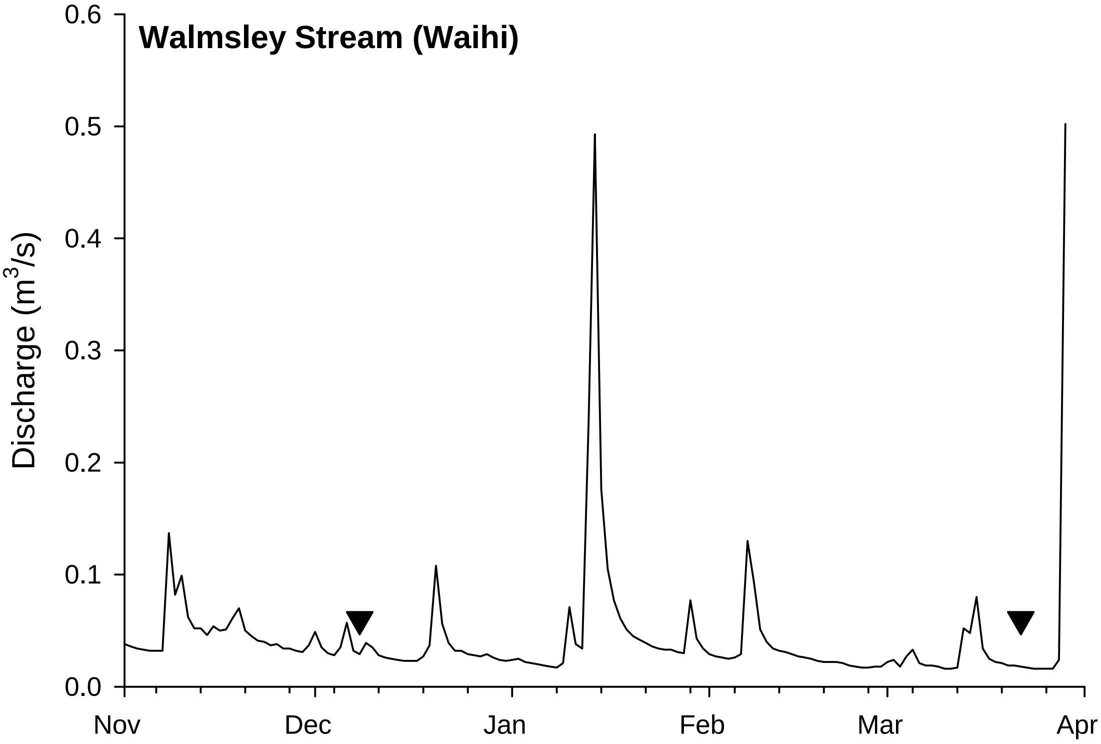
Mangarehu Stream (Thames)
Abstraction volume (m3/day)
5000
4000
3000
2000
1000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr

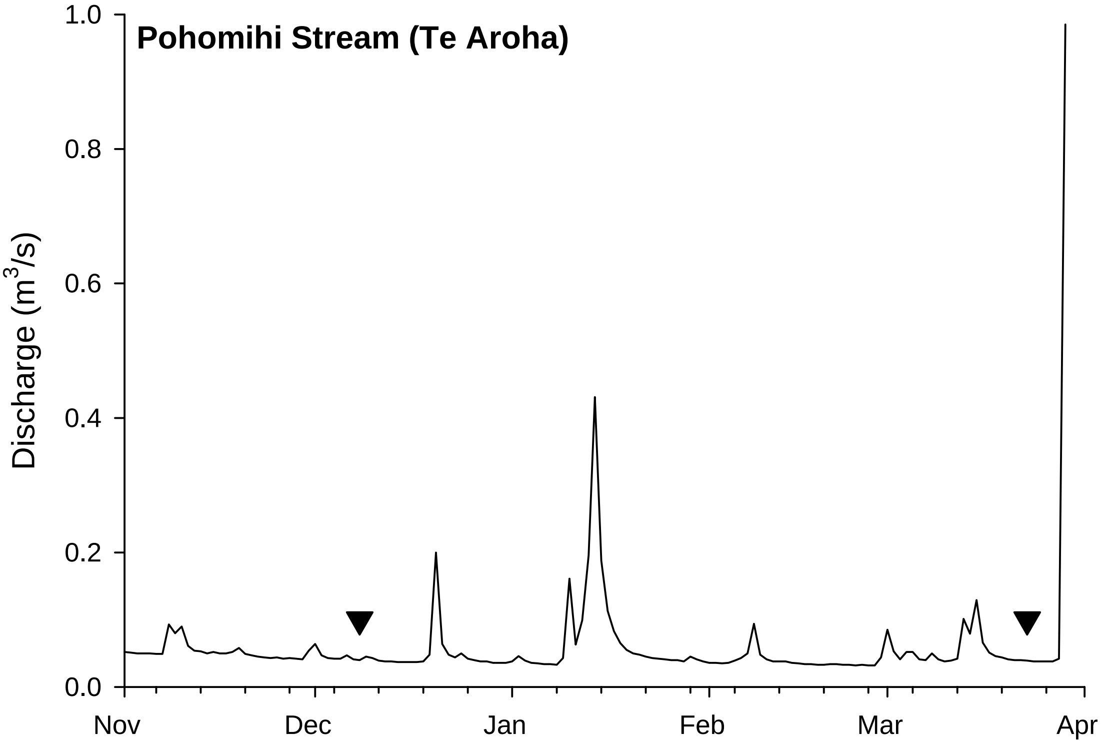
Appendix IV: Synthesised flows (m^3/s) for sites upstream of water supply intakes on each study stream between November 2006 and March 2007. Arrows on each hydrograph indicate invertebrate sampling times for each stream.

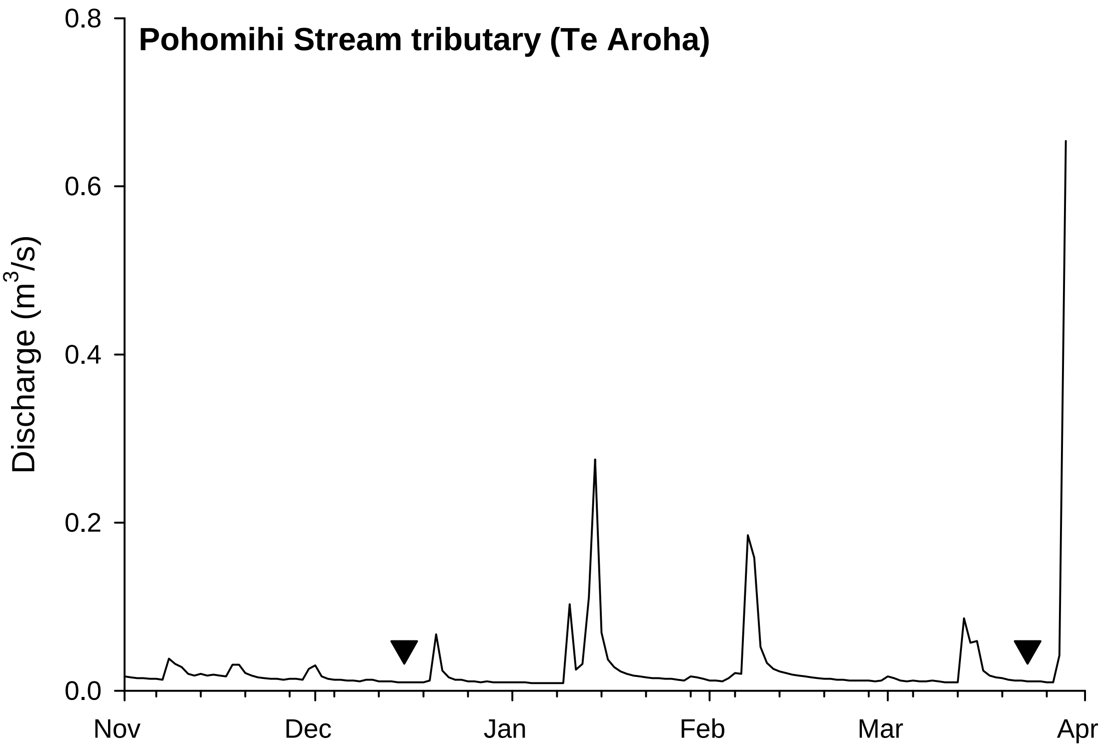


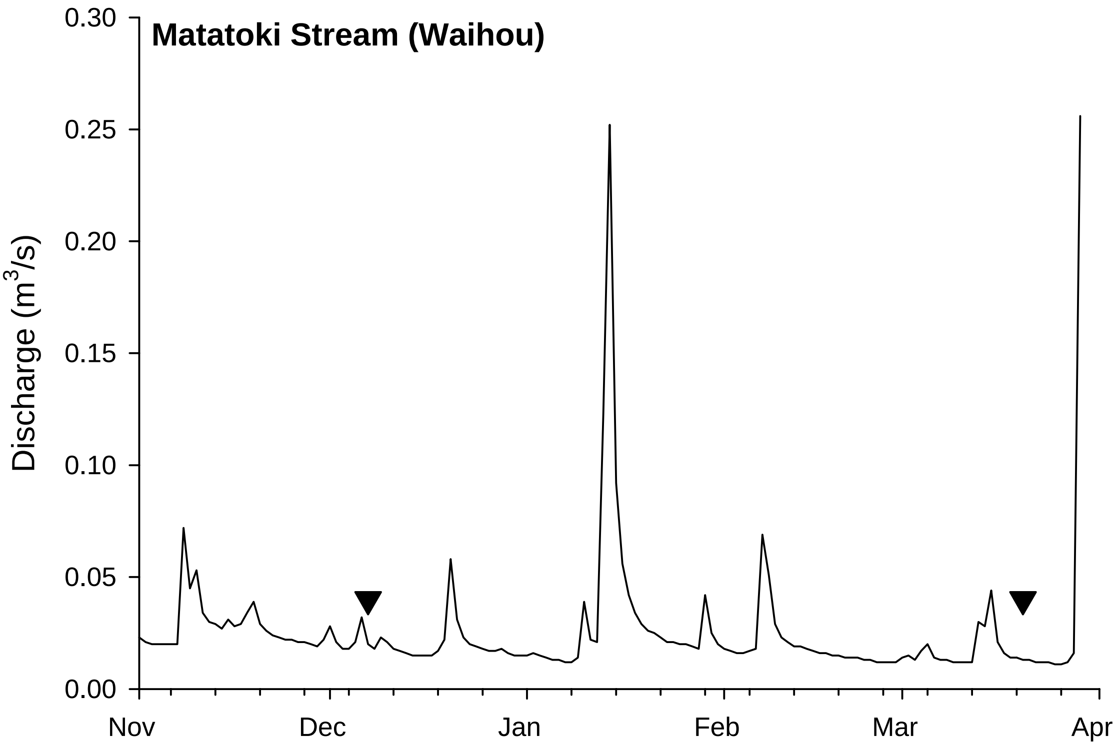

Oturu Stream (Tairua)
Discharge (m3/s)
2.5
2.0
1.5
1.0
0.5
0.0
Nov
Dec
Jan
Feb
Mar
Apr

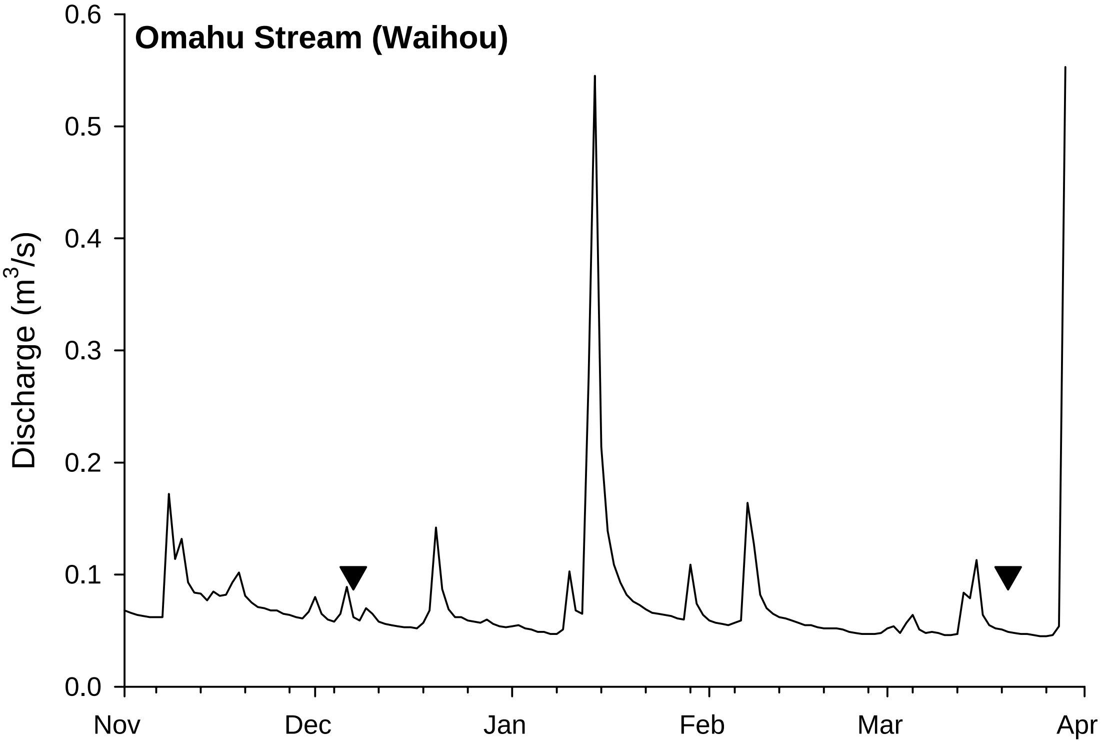

Waitete Stream (Waihi)
Discharge (m3/s)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Nov
Dec
Jan
Feb
Mar
Apr


Walmsley Stream (Waihi)
Discharge (m3/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Nov
Dec
Jan
Feb
Mar
Apr

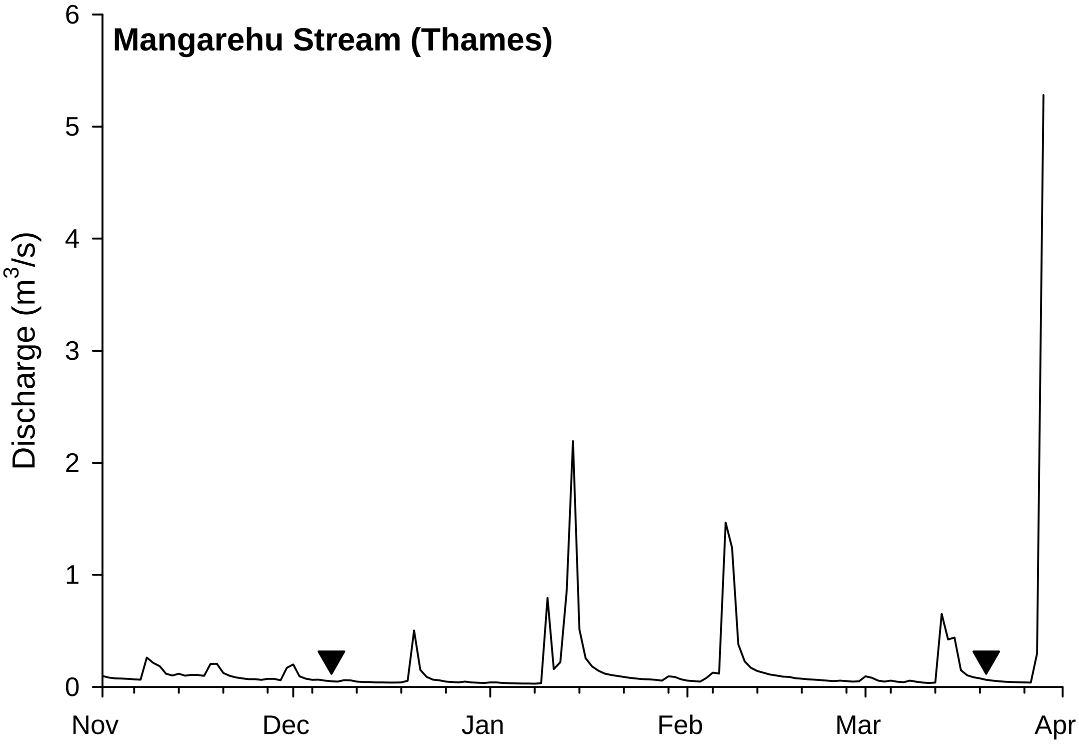

Pohomihi Stream (Te Aroha)
Discharge (m3/s)
0.0
0.2
0.4
0.6
0.8
1.0
Nov
Dec
Jan
Feb
Mar
Apr


Pohomihi Stream tributary (Te Aroha)
Discharge (m3/s)
0.0
0.2
0.4
0.6
0.8
Nov
Dec
Jan
Feb
Mar
Apr

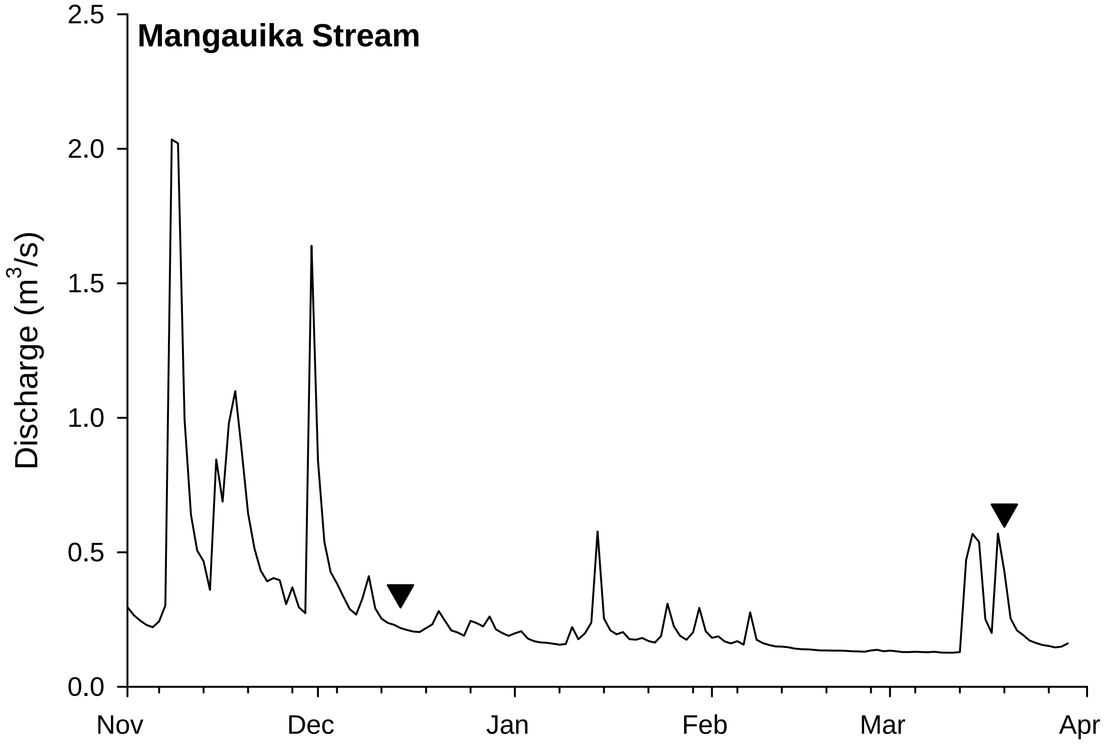

Matatoki Stream (Waihou)
Discharge (m3/s)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Nov
Dec
Jan
Feb
Mar
Apr



Omahu Stream (Waihou)
Discharge (m3/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Nov
Dec
Jan
Feb
Mar
Apr



Mangarehu Stream (Thames)
Discharge (m3/s)
0
1
2
3
4
5
6
Nov
Dec
Jan
Feb
Mar
Apr


Mangauika Stream
Discharge (m^3/s)
2.5
2.0
1.5
1.0
0.5
0.0
Nov
Dec
Jan
Feb
Mar
Apr

Appendix V: Average values of daily mean, daily maximum and daily minimum temperatures recorded for sites upstream and downstream of water supply intakes on each study stream between December 2006 and March 2007.

Stream	Mean temp. (°C)		Max. temp. (°C)		Min. temp. (°C)	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Waitete	14.1	14.4	14.7	15.2	13.5	13.7
Pohomihi	14.3	14.4	15.1	15.3	13.5	13.7
Pohomihi trib.	14.1	14.1	14.6	14.4	13.7	13.7
Mangarehu	16.1	16.3	18.1	17.8	14.7	15.2
Mangauika	13.3	13.3	14.4	14.6	12.3	12.2
Omahu	16.7	16.7	18.3	17.5	15.5	16.0
Pepe	16.8	17.0	18.4	18.5	15.5	15.7
Walmsley	15.0	15.6	16.8	17.5	13.6	13.9
Oturu	17.5	17.8	19. 6	19.5	15.8	16.4

Appendix VI: P-values for ANOVAs testing for differences between before and after summer (BA), control and impact sites (CI), and the interaction (BA×CI). The BA×CI interaction is the term of interest in this model. Results significant at the 1% level are displayed in red.

Stream		d.f.	Individuals	Taxa	% EPT individuals	% EPT taxa	MCI	QMCI	Chlorophyll *a*
Waitete	BA	1, 16	0.709	0.916	0.325	0.362	0.437	0.910	0.457
	CI	1, 16	0.447	0.001	<0.001	<0.001	<0.001	<0.001	0.044
	BA×CI	1, 16	0.027	0.058	0.738	0.701	0.669	0.639	0.395
Pohomihi	BA	1, 16	<0.001	0.013	0.152	0.122	0.406	0.239	0.725
	CI	1, 16	0.962	0.493	0.212	0.995	0.671	0.455	0.452
	BA×CI	1, 16	0.896	0.611	0.350	0.988	0.926	0.320	0.294
Pohomihi trib	BA	1, 16	0.498	0.722	0.012	0.227	0.176	0.090	0.331
	CI	1, 16	0.186	0.535	0.016	0.017	0.007	0.060	0.024
	BA×CI	1, 16	0.607	1.000	0.911	0.639	0.128	0.577	0.840
Mangarehu	BA	1, 16	0.155	0.945	0.002	0.315	0.757	0.024	0.721
	CI	1, 16	0.388	0.835	0.481	0.675	0.600	0.220	0.120
	BA×CI	1, 16	0.061	0.123	0.824	0.417	0.740	0.482	0.278
Mangauika	BA	1, 16	0.013	0.072	0.216	0.649	0.611	0.006	0.700
	CI	1, 16	0.936	0.247	0.103	0.597	0.273	0.005	0.202
	BA×CI	1, 16	0.275	0.350	0.483	0.170	0.126	0.109	0.279

Appendix VI (continued). P-values for ANOVAs testing for differences between before and after summer (BA), control and impact sites (CI), and the interaction (BA×CI). The BA×CI interaction is the term of interest in this model. Results significant at the 1% level are displayed in red.

Stream		d.f.	Individuals	Taxa	% EPT individuals	% EPT taxa	MCI	QMCI	Chlorophyll *a*
Omahu	BA	1, 16	0.017	0.083	0.013	<0.001	<0.001	<0.001	<0.001
	CI	1, 16	0.002	0.169	0.004	0.640	0.116	0.107	0.057
	BA×CI	1, 16	0.020	0.482	0.019	0.971	0.010	0.022	0.190
Pepe	BA	1, 16	0.077	0.048	0.419	0.320	0.017	0.780	0.010
	CI	1, 16	0.725	0.726	0.944	0.133	0.042	0.420	0.027
	BA×CI	1, 16	0.479	0.418	0.200	0.305	0.007	0.434	0.624
Matatoki	BA	1, 16	0.545	0.536	0.003	0.982	0.573	0.927	0.449
	CI	1, 16	0.703	0.536	<0.001	<0.001	<0.001	<0.001	0.015
	BA×CI	1, 16	0.010	0.202	0.084	0.031	0.060	0.001	0.694
Walmsley	BA	1, 16	0.006	0.573	0.117	0.039	0.005	0.139	<0.001
	CI	1, 16	0.139	0.161	0.221	0.142	0.397	0.056	0.927
	BA×CI	1, 16	0.405	0.850	0.642	0.941	0.299	0.761	0.961
Oturu	BA	1, 16	0.005	0.871	<0.001	0.204	0.308	0.476	0.145
	CI	1, 16	0.021	0.485	0.017	<0.001	<0.001	<0.001	0.141
	BA×CI	1, 16	0.025	0.265	0.002	0.286	0.192	0.575	0.980

Appendix VII: Mean (n = 5) values of invertebrate community metrics for upstream and downstream sites on ten streams in the Waikato Region, sampled in December 2006 and March 2007.

Stream	No. of animals		No. of taxa		% EPT individuals		% EPT taxa		MCI		QMCI	
	Dec	Mar	Dec	Mar	Dec	Mar	Dec	Mar	Dec	Mar	Dec	Mar
Waitete upstream	93	181	15	19	75.1	64.2	66.6	63.4	137	134	6.89	6.54
Waitete downstream	145	81	12	8	11.9	6.4	32.6	24.8	88	79	2.74	2.95
Pohomihi upstream	112	570	16	26	89.1	93.2	76.5	69.2	144	141	7.71	7.81
Pohomihi downstream	129	562	15	22	72.3	90.6	76.6	69.2	143	139	6.78	7.95
Pohomihi trib. upstream	324	312	20	21	93.8	87.7	68.8	66.7	144	145	7.91	7.75
Pohomihi trib. downstream	264	179	19	20	87.9	82.3	62.9	58.2	140	131	7.72	7.41
Mangarehu upstream	54	19	9	6	73.3	42.6	54.2	41.1	112	116	6.38	5.47
Mangarehu downstream	43	48	7	9	65.9	38.7	51.3	49.9	117	117	6.10	4.45
Mangauika upstream	272	207	18	16	92.1	91.2	72.6	66.4	147	139	7.92	8.08
Mangauika downstream	320	166	18	13	96.2	92.9	69.7	72.8	145	149	8.10	8.64
Omahu upstream	252	261	17	22	71.2	40.8	59.0	48.6	127	99	6.94	4.69
Omahu downstream	387	958	22	24	75.3	74.2	60.1	49.6	114	102	6.70	5.91
Pepe upstream	175	497	17	22	49.1	45.4	46.0	46.1	101	102	3.95	4.19
Pepe downstream	220	364	18	20	39.7	55.9	43.8	34.8	104	82	3.94	3.82
Matatoki upstream	181	467	18	24	71.9	45.2	66.2	58.9	132	127	7.14	6.05
Matatoki downstream	385	199	24	22	39.8	31.7	42.4	49.8	94	103	3.25	4.30
Walmsley upstream	62	202	13	13	38.1	26.2	45.8	35.8	110	91	4.85	3.55
Walmsley downstream	37	118	10	11	55.7	34.3	53.2	42.5	109	99	6.07	5.20
Oturu upstream	130	165	18	16	74.7	84.8	60.9	69.7	130	131	6.61	6.65
Oturu downstream	134	401	17	20	48.7	88.9	47.7	48.5	110	101	4.78	5.12