HAWKE'S BAY
REGIONAL COUNCIL

Life Supporting Capacity in Lowland Streams

With a focus on the Karamu Catchment

January 2016
HBRC Report No.   RM16-05 – 4782

Resource Management Group

ISSN 2324-4127 (PRINT)
ISSN 2324-4135 (ONLINE)

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Environmental Science - Water Quality and Ecology

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QUALITY
ISO 9001

ISSN 2324-4127 (PRINT)
ISSN 2324-4135 (ONLINE)

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Executive summary

The Karamu/Clive catchment on the Heretaunga Plains is one of New Zealand's most productive horticultural areas. Streams in the catchment have a low gradient and sandy/silty substrates, which provide ideal growing conditions for aquatic plants (macrophytes). The streams have been extensively modified, channelised and straightened for drainage and flood protection, and are currently suffering from nuisance macrophyte and algal growth.

Macroinvertebrate Community Index (MCI) scores here are amongst the lowest in Hawke's Bay, indicating the life supporting capacity in these streams is compromised. In the summer of 2013/14 an investigation was carried out to identify what particular factors are most detrimental to the ecological health of these streams.

Sixteen lowland stream sites with a range of environmental conditions were chosen for this study. Macroinvertebrates were sampled, along with water quality parameters, and stream habitat and macrophytes were assessed. Dissolved oxygen and water temperature were recorded continuously at the sites for several days.

At many sites macrophytes blocked more than half of the stream channel, and habitat quality was degraded. Temperature in some streams increased above 27°C and dissolved oxygen was extremely low for several hours each day. In these situations, ecosystem respiration (by plants, animals and microorganisms) consumes more oxygen in the stream than is produced by photosynthesis or derived from the atmosphere, leading to very low dissolved oxygen at certain times of day.

Analyses indicated that maximum water temperature, minimum dissolved oxygen concentration and habitat quality most strongly affected changes in macroinvertebrate community composition. Abundance of mayflies and caddisflies, and MCI scores were lowest at sites with high maximum temperature and low daily oxygen minima. These were the major factors compromising life supporting capacity in the study streams.

Therefore, the following factors need to be dealt with in order to improve ecosystem health across the Heretaunga Plains streams:

1. Water temperature can be reduced by providing shade to the stream channel where it does not exist. Overhanging riparian vegetation also creates a cooler microclimate above the stream channel further reducing temperature extremes.

2. Reduction in aquatic plant growth can limit the amount of oxygen depletion. This can be achieved by shading the stream channel, to reduce the light available for plant growth. Since macrophytes are relatively independent of dissolved nutrient concentration (as rooted plants they can acquire nutrients from the sediment) the management by limiting light availability can be more effective than through nutrient reduction.

3. Habitat quality is very poor in the highly modified, channelised, soft-sediment dominated streams of the Heretaunga Plains. Habitat complexity is a vital component of a healthy stream ecosystem and in soft sediment lowland streams is typically provided by stable substrate such as root mats, twigs and leaf-packs and large woody debris. These important habitat components are often provided by a healthy, mature overhanging riparian vegetation community.

Given these factors, establishment of overhanging riparian vegetation would be the most effective way to increase and improve the life supporting capacity in these streams: The shade provided by bankside vegetation prevents excessive macrophyte growth, thus reducing the frequency and severity of low oxygen minima events. Shade also controls stream temperature and reduces sunlight reaching the stream channel, creating a cooler microclimate above the water. Riparian vegetation also improves invertebrate and fish habitat, particularly in soft sediment lowland streams by providing for habitat complexity. Additionally a healthy riparian vegetation community improves bank stability, and reduces bacteria, sediment and nutrient inputs, further improving stream health.

1 Introduction

The Karamu catchment is 51,462 hectares extending south from Awatoto to Havelock North and west to the Raukawa Range. The Karamu Stream and its tributaries drain the Poukawa Basin, the Kohinurakau, Kaokaoroa and Raukawa Ranges and a large part of the Heretaunga Plains. Waterways in the Karamu catchment have been extensively modified for flood protection purposes. The lower part of the present-day Karamu Stream was once a former channel of the Ngaruroro River, until a large flood changed the course of the river. In 1969, as part of the Heretaunga Plains Flood Protection scheme, the Ngaruroro River was diverted to the north. Today the Karamu and Raupare streams combine to form the lower Karamu Stream, which is also known as the Clive River, or Ngaruroro Tawhito (the 'old' Ngaruroro).

The catchment includes most of the Heretaunga Plains, which has been developed extensively for agriculture and comprises some of the most productive cropping areas in New Zealand. The Karamu catchment is the main region in Hawke's Bay for orcharding, cropping, and viticulture. The southwest part of the catchment primarily supports dryland sheep and beef, with the exception of the Poukawa Basin, which is a significant cropping area (Figure 1-1). Water resources in the Karamu catchment have been developed for a variety of land uses, including orchards, crops, industry and town supply (HBRC 2014).

Streams in the Karamu catchment are classified as originating from lowland country in a warm dry climate, according to the New Zealand River Environment Classification REC (Snelder, Biggs et al. 2010). They are characterised by very low gradients with slow flowing water, with a streambed often made up of fine gravel or sandy/silty substrate. This provides ideal growing conditions for aquatic plants (macrophytes). By contrast, algae is more commonly found in streams with faster flowing, stony substrates.

1.1 Macroinvertebrate communities and life supporting capacity

Samples of aquatic macroinvertebrates such as insect larvae and snails have been collected annually since 2007 for the State of the Environment (SoE) monitoring programme.

Macroinvertebrate communities are commonly used as an indicator of water quality and ecosystem health. The macroinvertebrate community of a stream adjusts to conditions in the aquatic environment, including natural conditions and natural and artificial stressors affecting ecosystem health.

The macroinvertebrates are exposed to changes in conditions at a site for periods of months to years, depending on their life cycle. The community composition changes as sensitive species experiencing stress are lost, which leads to a community dominated by more tolerant species. Both natural changes (e.g. variability in climate causing floods or droughts) and changes caused by human activities (e.g. changes to streambed substrate type caused by erosion, water temperature changes caused by the removal of vegetation) may affect macroinvertebrate communities. Assessing the composition of macroinvertebrate communities provides a long-term integrated view of 'water quality'.

The Macroinvertebrate Community Index (MCI) was developed by Stark (1985) as a biomonitoring tool to assess stream health in New Zealand, based on the presence or absence of certain invertebrate species. The MCI index is derived by scoring individual taxa observed at a site based on their 'tolerance value' which is a taxon's sensitivity or tolerance to pollution, with higher scores for more sensitive taxa and lower scores for taxa tolerant to pollution: A higher MCI score therefore means more sensitive, pollution 'intolerant' species are present at a site, which indicates better river conditions. The MCI of a site can be used to assess the likely level of ecosystem degradation. The MCI summarises the complexity of stream health as a single numeric value that represents a wide range of factors. It is the most commonly used indicator of macroinvertebrate community health in large-scale monitoring and reporting in New Zealand, such as State of the Environment monitoring and reporting undertaken by Regional Councils and Territorial Local Authorities.

SoE monitoring sites across Hawke's Bay have MCI scores in all four environmental quality classes. The regional average MCI score of monitored sites is 104, with a regional maximum of 150. In the Karamu catchment 76% of the sites had MCI scores lower than 80 – and can be described as being of 'poor quality with probable severe pollution' (Stark and Maxted 2007). One third of these sites score below 60, ranking amongst the lowest MCI values nationally (HBRC 2014).

While usually 20 to 30 different taxa of varying pollution sensitivities are found at SoE monitoring sites, some Karamu catchment sites have less than 10 very pollution tolerant taxa that survive in these streams. This indicates that stream health is severely compromised, with low life supporting capacity because all pollution sensitive taxa have been lost from these sites.

A model has been developed that predicts MCI scores across New Zealand, based on data collected from hundreds of monitoring sites throughout the country provided by regional councils, NIWA, Cawthron Institute, and Otago, Canterbury and Massey Universities (Clapcott, Young et al. 2011). The model predicts MCI scores at SoE sites in the Hawke's Bay region that are close to measured scores, particularly for gravel streams and rivers in hill country areas. However, in the Karamu catchment observed MCI scores fell significantly below predicted scores (HBRC 2014). The Karamu monitoring sites were on average 26 MCI score points lower than predicted, with measured MCI scores at several sites being more than 40 points lower than predicted by the Clapcott, Young et al. (2011) model.

The Karamu catchment has a macroinvertebrate community that indicates extremely poor ecosystem health and low life supporting capacity, compared with both regional and national levels. In addition, the catchment sites appear to be affected more than the national model predicts for these streams, suggesting that pressure on the Karamu catchment streams is greater than is typically seen for lowland, soft-sediment dominated coastal streams elsewhere in the country.

1.2 Cumulative effects and multiple stressors – what limits life supporting capacity?

The possible causes of the poor macroinvertebrate community scores observed in the Karamu catchment are not immediately obvious. Macroinvertebrate communities and in turn MCI scores are influenced by multiple stressors that exert pressure on stream ecosystems in complex and interactive ways. Teasing apart specific factors that cause low MCI scores is challenging.

Water quality and quantity monitoring and SEV (Stream Ecological Valuations (Rowe, Quinn et al. 2006)) provided additional information regarding the environmental conditions at these sites. The SEV method uses 31 variables to assess stream condition. The variables are grouped into four categories - hydraulic, biogeochemical, habitat, and biodiversity. Potential stressors identified by the SEV process at sites in the Karamu catchment with very poor MCI scores included elevated nutrient concentrations, straightened channels, limited riparian shade, nuisance plant proliferation, stock access and low flows (Forbes and Cattin (2009); Cameron (2010); Forbes (2011); Stansfield (2009)).

A targeted investigation was undertaken in the summer of 2013/14 to provide detailed information on the multiple stressors that influence MCI in this system. The study aims included being able to identify one or several key factors that limit life supporting capacity, as the first step in identifying ways to improve stream ecological health.

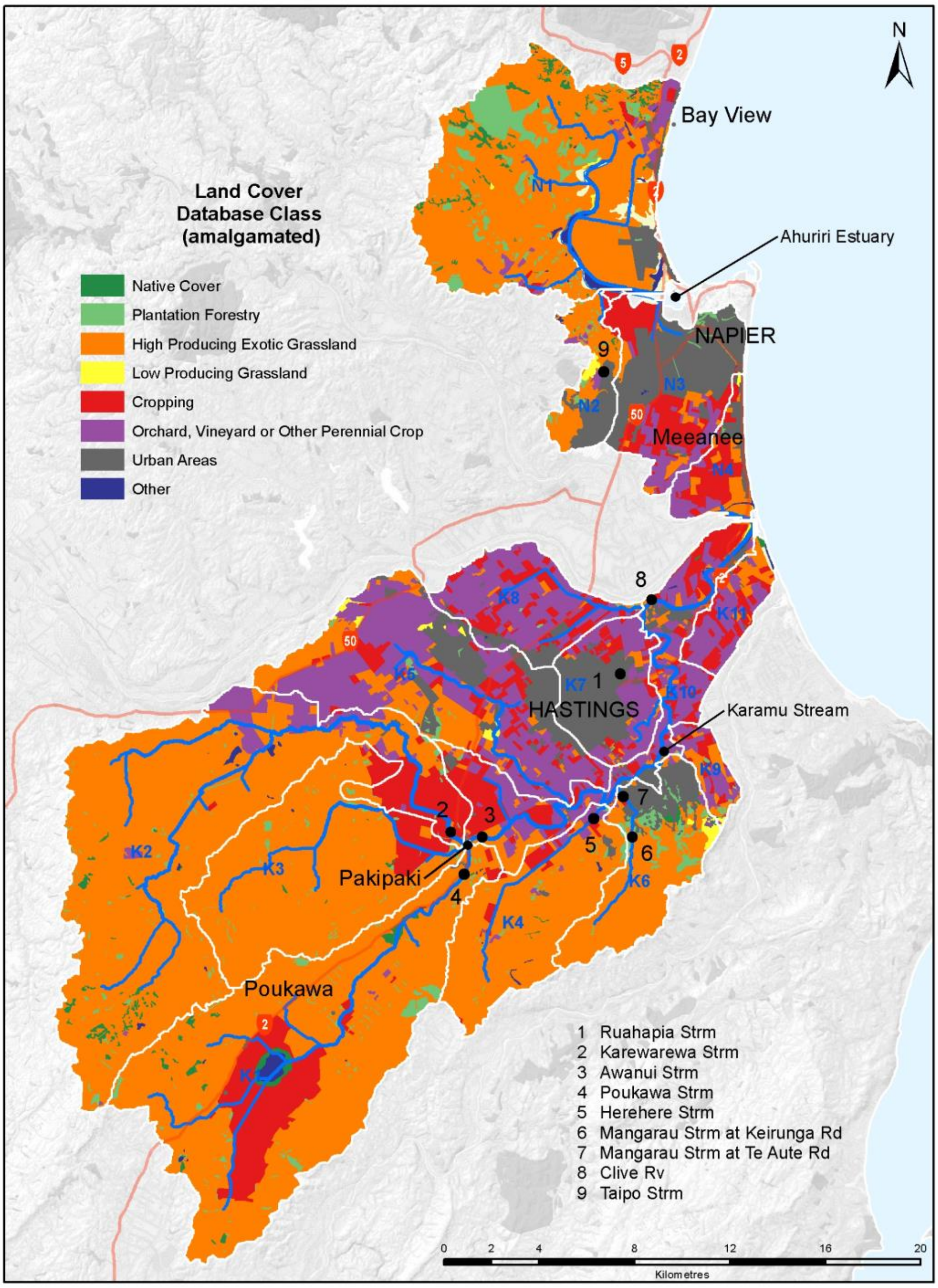


Figure 1-1: LDCB4 classification of the Karamu Stream and Ahuriri Estuary catchments. The Tutaekuri-Waimate and Papanui streams are not included in the map and lie in adjacent catchments directly north and south of the Karamu catchment.

2 Methods

2.1 Study design

The study design focused on the macroinvertebrate community as a 'response variable' being affected by environmental pressures, or 'predictor variables' (Figure 2-1). Variations in community composition of the study sites were examined across a range of environmental conditions. The predictor variables best correlated with observed changes in taxa abundance were sought. This can then indicate which of the potential stressors are most likely to cause the degraded macroinvertebrate communities found in some of the streams in the Karamu catchment.

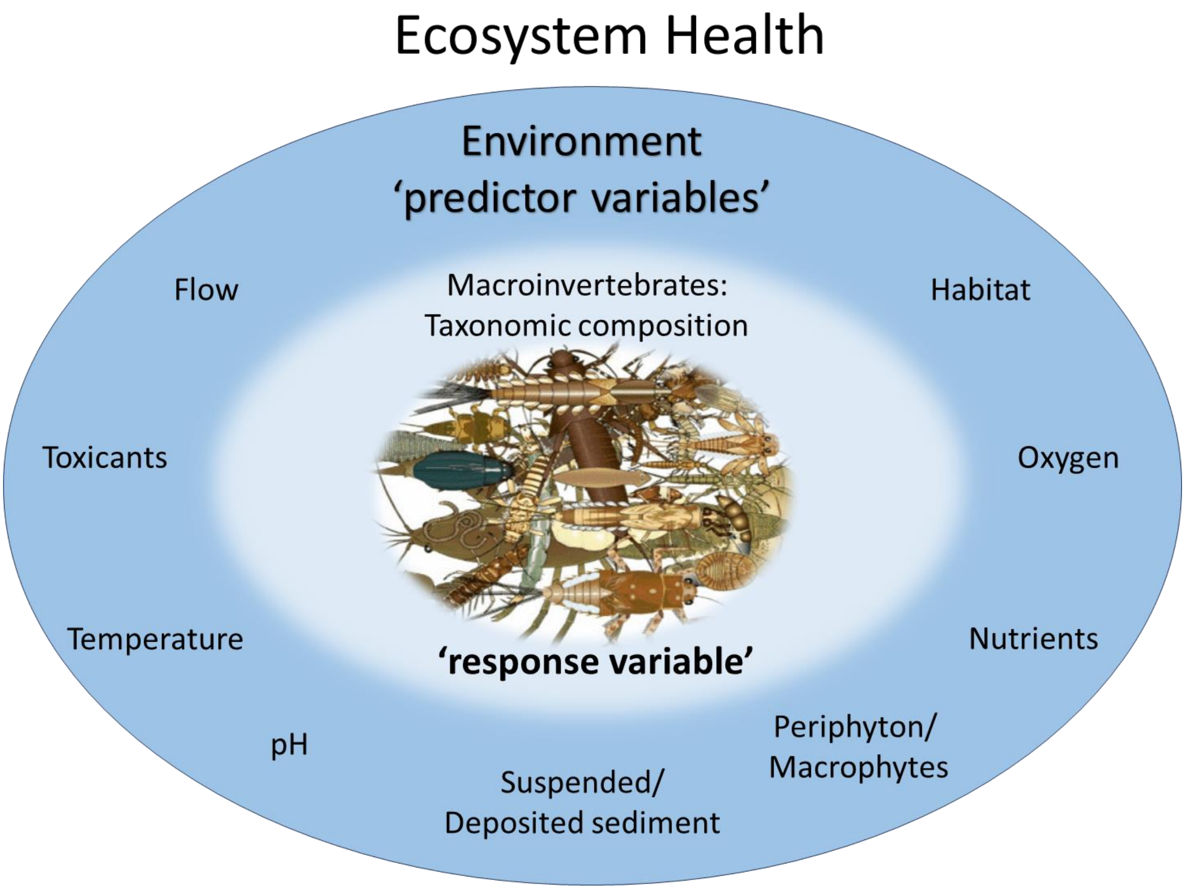


Figure 2-1: Schematic overview of the study design. Environmental parameters are used as predictor variables and the macroinvertebrate community composition as response variable in the statistical analysis.

Since the focus was on potential stressors, variability in natural 'background' variables were kept as low as possible. To assist in this, all study streams chosen were morphologically similar, being relatively small streams, with slow flow, less than 1 m deep, and with a low channel gradient. The streams had varying bed substrate composition (predominantly soft substrate with silt, sand and mud, but also a varying proportion of gravel). In order to remove the variability in this important habitat parameter, macroinvertebrates were only sampled from aquatic plants (macrophytes) across all sites, not from the streambed, which means that the sampled habitat was the same across all sites. To remove any impact from varying weather or flows, the sampling of all 16 sites was carried out over a short period of time during stable weather conditions. An overview on the response variables, the predictor variables and the background variables is given in Table 2-1.

Two remaining elements determined the selection of study sites: the range of MCI values, and the range of variation in potential environmental stressors on the macroinvertebrate community across the study sites.

Table 2-1: Variables assessed for statistical analysis on the influence of potential environmental stressors on the macroinvertebrate community composition.

Macroinvertebrate community (response variable)	Quantitative samples and indices (EPT value, %EPT, MCI, QMCI, MCI-sb, QMCI-sb)
Potential environmental stressors (predictor variables)	▪ Water quality: – Nutrients: total nitrogen, nitrate, dissolved inorganic nitrogen, (ammonia)[1], total phosphorus, dissolved reactive phosphorus; – pH; – Conductivity; – Turbidity; ▪ minimum, maximum, average, amplitude of dissolved oxygen ▪ minimum, maximum, average, amplitude of temperature ▪ Metabolism ▪ Macrophyte abundance: cross sectional area, surface area ▪ Habitat ▪ Flow velocity in sample reach
Background data (not included in analysis)	▪ Pesticide residues in sediment[2] ▪ Channel width, depth ▪ Channel bed substrate composition ▪ Shade ▪ Radon (to detect groundwater influence, only sites with potential input) ▪ Air temperature

[1] Ammonia concentrations not included in analysis as generally below limits of detection.
[2] Pesticide concentrations not included in analysis as generally below limits of detection.

2.2 Study sites

Sixteen sites that covered a gradient in MCI values were chosen for the study. All sites were of a similar stream type: macrophyte dominated lowland streams characterised by very gentle downstream slopes and gentle catchment gradients (FENZ classification in Leathwick, Julian et al. (2010)), fine bed substrates mostly of silt, sand and sometimes fine gravel. All sites were located within a 20 km radius: 11 sites in the Karamu Stream catchment, 1 in the Ahuriri catchment, 2 sites in the lower Ngaruroro catchment and 2 sites in the lower Tukituki catchment (Figure 2-2). The 16 sites provided for a range of environmental factors necessary for effective statistical analysis, and to aid in teasing apart specific stressors influencing the macroinvertebrate community.

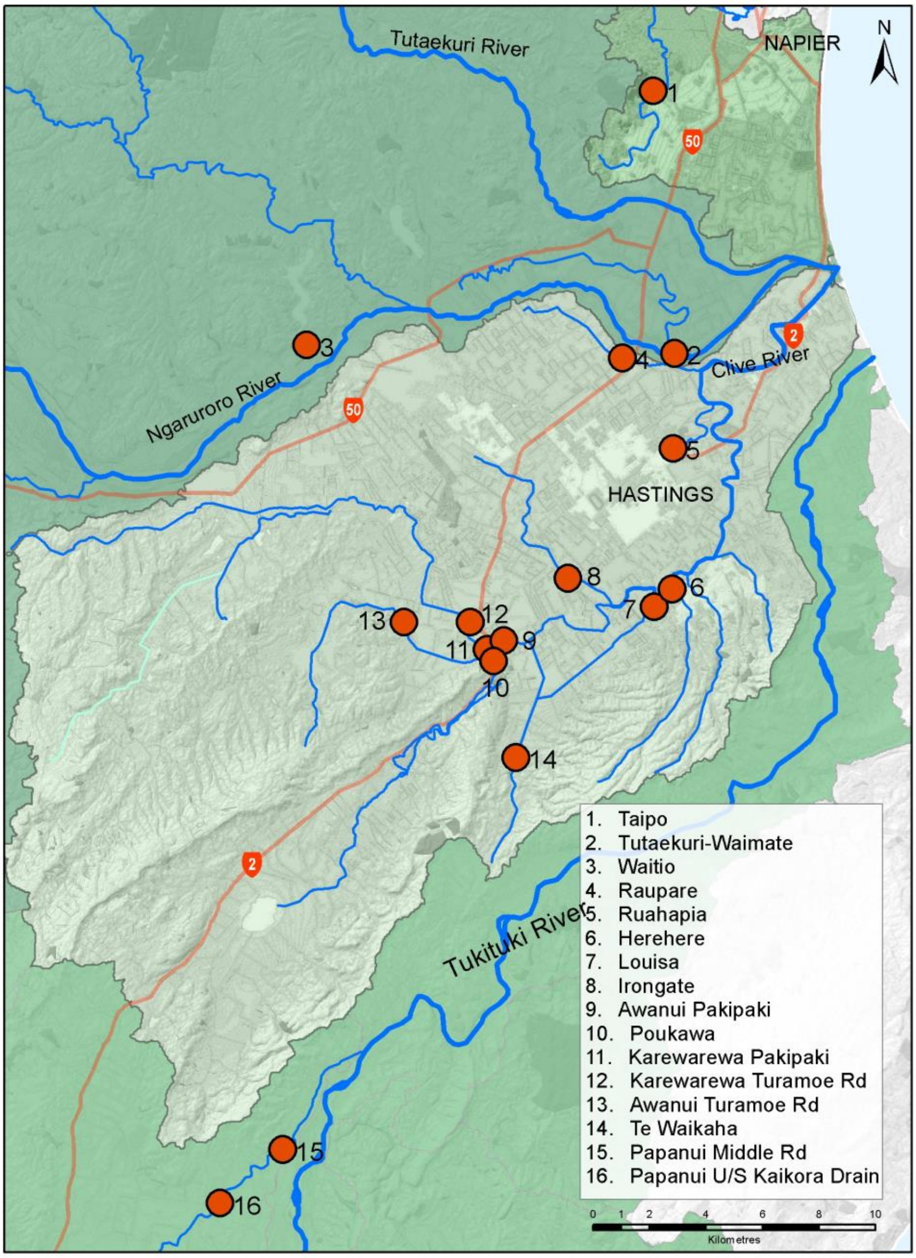


Figure 2-2: Map of study sites.

Most sites were State of the Environment sites with long-term water quality data. For 3 study sites background information was available from Stream Ecological Valuations (SEV) carried out between 2010 and 2012 or from historic SoE data. Only 4 sites selected for this study had no additional ecological or historic background information available (Table 2-2).

Photos of the study sites and their location in NZTM are included in Figure 2-3. The beds of the Raupare, Awanui, Irongate, Taipo, and Louisa streams were dominated by soft sediment including sand, silt and mud. The remaining sites had a combination of sand, silt, mud and gravel in varying proportions (Ruahapia, Poukawa, Karewarewa, Herehere, Papanui, Tutaekuri-Waimate, Waitio, and Te Waikaha streams).

Raupare Stream at Ormond Road.
NZTM: E1929880 N5609666
Karamu catchment

Ruahapia Stream at Showgrounds
NZTM: E1931666 N5606458
Karamu catchment

Karewarewa Stream at Turamoe Road
NZTM: E1924486 N5600299
Karamu catchment

Karewarewa Stream at Pakipaki
NZTM: E1925076 N5599339
Karamu catchment

Awanui Stream at Turamoe Road
NZTM: E1922131 N5600299
Karamu catchment

Awanui Stream at Pakipaki
NZTM: E1925675 N5599637
Karamu catchment

Irongate Stream at Riverslea Road
NZTM: E1927952 N5601866
Karamu catchment

Poukawa Stream at Stock Road
NZTM: E1925313 N5598912
Karamu catchment

Te Waikaha Stream upstream of Mutiny Road
NZTM: E1926089 N5595511
Karamu catchment

Louisa Stream at Te Aute Road
NZTM: E1930993 N5600842
Karamu catchment

Hererhere Stream at Te Aute Road
NZTM: E1931639 N5601475
Karamu catchment

Waitio Stream at Ohiti Road
NZTM: E1918690 N5610114
Ngaruroro catchment

Tutaekuri-Waimate Stream at Chesterhope
NZTM: E1931723 N5609827
Ngaruroro catchment

Taipo Stream at Church Road
NZTM: E1930966 N5619129
Ahuriri catchment

Papanui Stream upstream of Kaikora Drain
NZTM: E1915615 N5579699
Tukituki catchment

Papanui Stream at Middle Road
NZTM: E1917832 N5581608
Tukituki catchment

Figure 2-3: Study sites of lowland streams in the Karamu, Ngaruroro, and Tukituki catchments.

The streams at the study sites averaged 4.5 m wide and 0.4 m deep (Table 2-2), with the smallest streams being the Ruahapia and Herehere in both width and depth. The widest stream was the Waitio at 8 m wide and 0.26 m average depth and the deepest stream the Tutaekuri-Waimate at 0.77 m average depth and 6 m wide. Flow velocity was slow, ranging from almost stagnant in the Taipo (0.009 m/s) to 0.29 m/s in the Waitio. On average the flow velocity was 0.12 m/s across the study sites.

Table 2-2: Study sites, location and site details. Study Dataset: assessed for the study and additional data available- SoE: State of Environment monitoring site with long-term data; SEV: site with Stream Ecological Valuation data; Study: one-off sampling for this study, no additional data. Channel width, depth, flow velocity: Measurements at sampling date only, values are averaged over 5 transects along a 100m stream reach, flow velocity measured at 3 points across each transect. U/S = upstream.

Stream	Location	Catchment	Study Dataset	Channel width (m)	Channel depth (m)	Flow velocity (m/s)
Raupare	at Ormond Road	Karamu / Clive	Study	5.1	0.62	0.252
Ruahapia	at HB Showgrounds	Karamu / Clive	SoE	2.3	0.23	0.101
Irongate	at Riverslea Road	Karamu / Clive	SEV	5.3	0.23	0.272
Karewarewa Turamoe Rd	at Turamoe Road	Karamu / Clive	Study	4.7	0.33	0.151
Karewarewa Pakipaki	at Pakipaki	Karamu / Clive	SoE	3.1	0.27	0.068
Awanui Turamoe Rd	at Turamoe Road	Karamu / Clive	Study	4.6	0.37	0.022
Awanui Pakipaki	at Pakipaki	Karamu / Clive	SoE	4.6	0.56	0.060
Poukawa	at Stock Road	Karamu / Clive	SoE	4.9	0.67	0.009
Te Waikaha	at Mutiny Road	Karamu / Clive	SEV	3.1	0.27	0.177
Louisa	at Te Aute Road	Karamu / Clive	SEV	4.0	0.37	0.131
Herehere	at Te Aute Road	Karamu / Clive	SoE	2.4	0.12	0.106
Waitio	at Ohiti Road	Ngaruroro	SoE	8.1	0.26	0.285
Tutaekuri-Waimate	upstream Ngaruroro	Ngaruroro	SoE	6.3	0.77	0.191
Papanui U/S Kaikora Drain	upstream Kaikora Drain	Tukituki	Study	4.2	0.42	0.025
Papanui Middle Rd	at Middle Road	Tukituki	SoE	6.4	0.41	0.016
Taipo	at Church Road	Ahuriri	SoE	3.8	0.49	0.009

2.2.1 Sampling outline

Sampling was carried out over 20 days during dry, stable weather conditions starting 11th February 2014. Dissolved oxygen and temperature loggers were deployed at two to three sites in parallel for a minimum of 2 days. At the end of each logging period water quality and macroinvertebrate samples were taken and habitat and macrophyte assessments carried out (dates shown grey in Appendix A). The loggers were then transferred to the next set of sites (deployment periods P1 to P6). Both the Raupare at Ormond Road and Awanui at Pakipaki sites have permanent dissolved oxygen loggers installed that were compatible with loggers used for the short-term deployments at the remaining sites.

2.3 Macroinvertebrates (response variable)

The objective of this study was to determine specific environmental stressors or 'predictor' variables that influence macroinvertebrate community composition. Each site was sampled in a consistent manner that removed as many confounding[3] variables as possible. Habitat type is one such confounding variable that can influence macroinvertebrate community composition, independent of any stressor variables. To control for this, macroinvertebrates were sampled in a repeatable and consistent fashion only from macrophytes, which were present at all sites.

Macroinvertebrates were sampled from macrophytes in three pooled replicates using a Surber sampler. In order to standardise the sample size across sites as much as possible, the stream invertebrates were dislodged by brushing off the same volume of plant material, i.e. the volume described by the height and width of the Surber sampler over 0.5 m sample length (adapted from Protocol C4 in (Stark, Boothroyd et al. 2001) Stark *et al*. 2001). Macroinvertebrates were sampled only from macrophytes, even if other habitat types were present at the study site. This meant that the habitat 'type' and method of sampling was comparable across all sites.

The abundances of taxa found at the 16 sites was used in a multivariate statistical analysis (see 2.6.1) as response variables to environmental stressors.

Furthermore several invertebrate indicator metrics were calculated from the macroinvertebrate community found at each site. The metrics calculated were:

MCI-sb*	Presence/absence of sensitive and tolerant taxa, (sb: index for soft-bottom streams)
QMCI-sb**	Quantitative abundance of sensitive and tolerant taxa, (sb: index for soft-bottom steams)
Taxa richness	number of taxa present at a site
EPT taxa richness	number of EPT taxa[4] present at a site
% EPT taxa	proportion of EPT taxa[4] of all taxa present at a site
Taxon abundance	total number of individuals present
EPT taxon abundance	total number of EPT individuals present

*The macroinvertebrate community found in naturally soft-bottomed streams dominated by fine sediments, woody debris and macrophytes (due to a low stream or catchment gradient) is different to that found in hard bottomed streams, even under pristine conditions. As a result, MCI data collected from soft bottomed streams may overstate the degree of degradation compared with hard bottomed streams (Stark and Maxted 2007). Stark and Maxted (2007) calculated specific taxa scores for a separate index for soft-bottomed streams (MCI-sb), accounting for the natural conditions in these streams. The final scores

[3] A confounding variable is a variable, other than the independent (stressor) variable(s) that may affect the dependent variable (macroinvertebrate community composition). This can lead to incorrect conclusions about the relationship between the independent (stressor variables) and dependent variable (macroinvertebrate community composition).

[4] EPT taxa belong to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) and consist predominantly of taxa sensitive to pollution.

indicate the same water quality classes as the MCI, only the tolerance scores for taxa from which it was derived are different.

**The QMCI and QMCI-sb indices use the abundances of all taxa present, as number of individuals per taxon (MCI is an average score calculated from the presence or absence of a taxon) and quantitative macroinvertebrate community data is necessary for the calculation of this index.

MCI and MCI-sb scores sites can be categorised into four environmental quality classes as defined by Stark & Maxted (2007) (Table 2-3)

Table 2-3: MCI and QMCI quality classes as defined by Stark and Maxted (2007).

MCI MCI-sb	QMCI QMCI-sb	Class
> 119	≥ 6	Excellent quality, clean water
100 - 119	5 – 5.99	Good quality, possible mild pollution
80 – 99	4 – 4.99	Fair quality, probable moderate pollution
< 80	< 4	Poor quality, probable severe pollution

2.4 Environmental stressors (predictor variables)

2.4.1 Water quality and pesticide samples

Water quality grab samples were collected from a well-mixed point mid-stream at the end of the deployment period for dissolved oxygen and temperature loggers (the sampling date for each site is listed in Appendix A) Sediment samples for pesticide residue analysis were collected at the same time as water quality grab samples.

Water and sediment samples were sent to R.J Hills Laboratories (Hamilton, NZ) for analysis. Water quality samples were analysed for total nitrogen, total ammoniacal nitrogen, nitrite, nitrate, total Kjeldahl nitrogen (TKN), dissolved reactive phosphorus and total phosphorus. Sediment samples were tested for pesticides.

Dissolved oxygen (for logger calibration), conductivity and pH were measured using a handheld water quality meter (YSI Pro Plus); and turbidity was measured with a Hach 2100Q turbidity meter.

2.4.2 Continuous oxygen and temperature recording

The sites at Raupare at Ormond Road and Awanui at Pakipaki have Zebratech D-Opto data loggers installed long-term. Archived recordings were downloaded from HBRC's environmental monitoring database Hilltop. For maintenance and calibration procedures see (Wilding 2015). For remaining sites, standalone battery powered Zebratech D-Opto data loggers were deployed.

Calibration of the battery-powered Zebratech D-Opto data loggers was carried out in the HBRC laboratory and consisted of a two-point calibration using Na_2SO_3 solution for 0% dissolved oxygen and over-night aerated water for 100% dissolved oxygen in line with manufacturers recommendations. Once in the field, loggers were checked against an independent DO field meter (YSI Pro Plus), and if necessary a single-point calibration carried out at each successive site of deployment using a 100% air-saturated stream water solution. This was achieved by tipping stream water 20 times between two buckets as recommended by Wilcock, Young et al. (2011) .

Data loggers were programmed to log dissolved oxygen concentration (mg/l), dissolved oxygen saturation (%) and water temperature (^{o}C) at 15 minute recording intervals. They were deployed at each site over time periods of two or more days as specified in Appendix A.

Dissolved oxygen and temperature recordings were checked for data spikes. Outliers such as single 'zero' readings and erroneous data spikes were replaced by the average of the preceding and following data point. Data periods used for analysis were always covering at least one or more full 24-hour period from 0:00 to 23:45. Dissolved oxygen and temperature minima and maxima were calculated from 2-hour moving averages (8 data points of 15 min reading intervals) over the recording period at each site.

To compare the measured temperature regime to proposed NOF thresholds (Davies-Colley, Franklin et al. 2013) the Cox-Rutherford Index (CRI) (average of the daily mean and maximum temperature) was calculated for the temperature logger deployment periods of 2 to 3 days. This does not fully meet the criteria for calculating the CRI in Davies-Colley, Franklin et al. (2013) which is based on the 5 hottest days from a continuous measurement, but a comparison to the proposed thresholds with data from 2 to 3 days can give an indication in which NOF band the sites are likely to fall.

2.4.3 Ecosystem Metabolism

Ecosystem metabolism provides information on the food base in a stream, which is an indicator for ecosystem health, and helps determine instream life-supporting capacity (Young, Matthaei et al. 2008).

Stream metabolism values were calculated using the River Metabolism Estimator Version 1.2 (Young and Knight 2005).

The River Metabolism Estimator calculates the mean daily ecosystem respiration and production per unit volume. Using night-time continuous dissolved oxygen data (observed when light intensity was less than 2 µmol/m^2/s), ecosystem respiration (ER) and the reaeration coefficient (k) are calculated using the night time regression method (Owens 1974). The rate of change of oxygen concentration over short periods of time is regressed against the oxygen deficit, which is defined as the difference between the oxygen concentration at saturation and observed oxygen concentrations. Gross primary production is then calculated as the sum of temperature adjusted photosynthetic rates during daylight, using the calculated night time ecosystem respiration and reaeration coefficient (Young, Townsend et al. 2004). Stream metabolism was calculated for each day (24-hour-period) separately, and daily metabolism results with a threshold $R^2 > 0.4$ (a threshold recommended in the instructions for the River Metabolism Estimator of (Young and Knight 2005) were averaged for each site.

In some instances, to allow for metabolism calculations to be made from 'noisy' dissolved oxygen data, recordings that showed short-term spikes of unknown origin were smoothed by using 2-hour moving averages. This was done for the Herehere Stream, Karewarewa Stream, Poukawa Stream, Irongate Stream, and Papanui Stream at Middle Road.

2.4.4 Macrophyte assessment

Macrophytes were assessed using the macrophyte monitoring field sheet in the MfE report "Review of the New Zealand Instream Plant and Nutrient Guidelines" (Matheson, Quinn et al. 2012). Plant abundance is assessed as a visual estimate of percent of channel cross-sectional area/volume (CAV) or percent water surface area (SA) occupied. Plant species found at the study sites were listed, but not separately assessed as proportional area or volume of individual species.

The macrophyte assessment at each site were calculated from observations made over 5 transects spaced equidistantly over a 100 m stretch.

The Tutaekuri-Waimate site was not able to be safely waded because the water was too deep at 0.8 m, in combination with deep soft sediment. Sampling was therefore restricted to about a third of the stream width. Depth measurements were taken by tying a weight to the end of a tape measure, which was attached to a rod; the tape was held over the stream centre, reading off the depth the weight sank to when it reached the top of the streambed.

2.4.5 Habitat assessment

The Rapid Habitat Assessment Protocol (RHAP) developed by Clapcott (2013) was used for habitat characterisation of the sites (Appendix F). Nine habitat categories relevant to macroinvertebrates and fish are included in the assessment, being fine sediment deposition, invertebrate habitat, fish cover, hydraulic heterogeneity, bank stability, bank vegetation, riparian buffer width, riparian shade, and channel alteration. Each category is scored separately on a scale of 1 (worst) to 20 (best), whereas the two categories invertebrate habitat and fish cover score on a scale of 1 (worst) to 40 (best), and the scores are then combined to a single 'habitat score'.

The fine sediment deposition parameter only applies to hard bottomed streams, so it was ignored in this study, which considered mostly soft bottomed streams. Removal of the fine sediment deposition parameter from consideration means that the highest score available in this study is 200 points (Table 3-4).

2.5 Background variables

2.5.1 Stream morphology: Channel width, depth, flow velocity, bed substrate composition

At each of the 5 transects where macrophytes were assessed, stream width was measured, and an evenly spaced 11-point depth profile from stream bank to stream bank was taken. At sample points 3, 6 (centre) and 9 flow velocities were measured using a flow tracker (Sontek Handheld ADV). At the centre of each transect stream shading was measured using a densiometer. Bed substrate composition was assessed as visual estimates over the study reach.

2.5.2 Air temperature

Air temperature and light data for the study period were obtained from the HBRC climate station in Bridge Pa. The weather was dry and stable over the study period, but overcast weather for several days from 25th February 2014 onwards affected deployment periods P5 and P6, when lower air and water temperatures than usual during the monitoring period were experienced (Appendix B).

2.5.3 Groundwater influence

Sites that were considered to be potentially influenced by groundwater were tested for Radon as an indicator for groundwater coming in locally at the site (sites tested are listed in Appendix D).

The radon samples were collected in 20 mL sample bottles with minimal contact with air to prevent the radon sample from degassing.

Water samples were sent to GNS Science for analysis. For radon analysis the direct count Liquid Scintillation Counting (LSC) method was used. Equal volumes of the sample water and a photon emitting scintillation cocktail are mixed in a 20 mL vial scintillation vial. The vial is then placed in a low level scintillation counter where each sample is measured for 100 minutes. Radon is then calculated from the measured alpha decays from radon and it's two daughter products, 218Po and 214Pb in a sample, relative to a calibrated standard to obtain the absolute concentration in becquerels per litre (BqL-1).

2.6 Data analysis

2.6.1 Statistical Analysis

The objective of this study was to explore the relationship between the macroinvertebrate community and environmental variables (potential stressors). As with all organisms in nature, macroinvertebrates are adapted to their environment in a species-specific way, and will thrive or decline in abundance depending on whether the environmental conditions are close to their optimum or not. Looking at the relationship between species abundances and environmental gradients across a set of study sites helps to identify if an environmental variable is a stressor. If it is then the abundance of sensitive species decline, and tolerant species dominate the community.

Indicator systems using the presence or absence of taxa with specific sensitivity or tolerance include both the Macroinvertebrate Community Index (MCI) and the MCI for soft bottom streams (MCI-sb), calculated respectively from the composition of the macroinvertebrate community at hard bottomed and soft bottomed sites. The MCI and MCI-sb are national scoring systems which allocate a score from 1 to 10 for each species or taxon of macroinvertebrate, depending on their tolerance of (low score) or sensitivity to (high score) organic pollution. Since the MCI was developed to indicate eutrophication (i.e. the resulting lack of oxygen in the water), it is not suitable to identify unknown stressors which potentially cause the poor macroinvertebrate communities found in the lowland streams of this study. For this an analysis was chosen that explores the changes in abundances of all occurring taxa in relation to gradients of multiple environmental variables.

As a first step in this analysis Cluster Analysis (Primer 6 Version 6.1.16) was used to explore differences in macroinvertebrate communities across sites. Bray-Curtis similarity defines similarities within groups and dissimilarities between groups. This method examines the contribution of each variable (taxon) to average resemblances between sample groups. For Bray-Curtis similarities it determines the contributions to the average Bray-Curtis dissimilarity between groups of samples. (SIMPROF permutation test with 999 permutations, $p<0.05$).

To explore the relationship between all macroinvertebrate taxa and multiple potential stressors nonmetric multidimensional scaling (NMDS) was used, which examines the relationship between response or 'dependent' variables (the macroinvertebrates) and multiple predictor (or 'independent') variables (potential stressors). NMDS was performed using Primer 6 (Version 6.1.16). Species data was log(x+1) transformed to down weigh (i.e. reduce the significance) high abundance species, and unconstrained ordination was performed using Bray-Curtis distance.

The strength of environmental correlations was tested using the Spearman Rank correlation and selected for a correlation of >0.6. In a second step the environmental variables (stressors) that were identified to have a significant effect on the macroinvertebrate community were then tested against indicator metrics commonly calculated from the community composition. For this a simple linear regression was used to visualise how strongly these metrics correlate with the stressors.

3 Results

3.1 Water quality, pesticides

3.1.1 Pesticides

NOTE: Sediments in aquatic systems are important as both sink and source of dissolved contaminants. Bioavailable contaminants from sediment can have an impact on benthic biota, and hence potentially on the aquatic food chain. Accumulation of contaminants can be a threat to ecosystem health (ANZECC 2000). For aquatic ecosystems of high ecological value, chemicals originating from human influence should be undetectable, which is the recommended precautionary approach in the ANZECC (2000) guidelines.

Out of the 173 pesticide components tested in this study only 23 contaminants have recommended sediment quality guidelines for New Zealand. Therefore pesticide residues in sediment found above detection limits in this study will merely be interpreted as identification of a potential risk of an adverse effect on ecological health.

Most of the 173 pesticide components tested for at each site were below detection limits. The complete results of the pesticide analysis can be referred to in Appendix A. Pesticide residues above detection limits were found in the Taipo and the Ruahapia streams at the following concentrations:

Taipo:

- **Diuron** (3,4-dichloroaniline): 0.009 mg/kg dry weight

Diuron is a herbicide that inhibits photosynthesis and is used for example as herbicide, anti-fouling agent and algicide in the construction sector. The product reacts with humic substances in soils and sediments where it accumulates due to its low biodegradation rate (estimated half-life 1,000 days). In Europe it is classified as dangerous for the environment[5], being very toxic to aquatic organisms, and since it may cause long-term adverse effects in the aquatic environment (European_Commission 2006). There are no guidelines for Diuron concentration in sediments in New Zealand, and the risk for the aquatic ecosystem at the concentration found here is unknown.

Ruahapia:

DDT: Dichlorodiphenyltrichloroethane (DDT) and its metabolites DDE (Dichlorodiphenyldichloroethylene), DDD (Dichlorodiphenyldichloroethane):

- **4,4'-DDD** 0.015 mg/kg dry weight
- **4,4'-DDE** 0.011 mg/kg dry weight
- **4,4'-DDT** 0.028 mg/kg dry weight

[5] The classification of the substance is established by Commission Directive 2004/73/EC of 29 April 2004 (29th ATP) adapting to technical progress for the 29th time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances, OJ. L 152 of 30/04/2004.

- **Diphenylamine** 0.08 mg/kg dry weight

DDT was used as an insecticide for public health purposes in World War II (to control the vectors for malaria, typhus and other diseases), on food crops, and for insect control in livestock, buildings and gardens. It is persistent in the environment, accumulates in fatty tissues and can travel long distances in the upper atmosphere (NPIC 2000). In the 1070s and 1980s the use of DDT was banned in most developed countries due to concerns over its toxicity and carcinogenic nature in humans, and over its environmental effects.

Diphenylamine is used, for example, as an indoor drench treatment for apples, and derivatives are used as lubricant, fungicide, and antioxidant. The substance is rated as dangerous to the environment and very toxic to aquatic organisms, and may cause long-term adverse effects in the aquatic environment (European_Chemicals_Bureau 2008).

Concentrations of DDT, DDE and DDD and Diphenylamine above detection limits in the sediment of the Ruahapia Stream show that there is a potential risk for the aquatic ecosystem. There are not enough data to determine if organisms in the stream are directly affected by the concentration found in the sediment, this would need further investigation.

3.1.2 Nutrients

The box plots in the following chapters on water quality have two sets of data. The boxes and whiskers show long-term water quality from current and historic SoE data. The red dots are single water quality samples taken on the same day ecological assessments for the current study were made. This helps to put the water quality sample into the context of long-term results for sites with SoE data. The Irongate Stream, Karewarewa Stream at Turamoe Road and Awanui Stream at Turamoe Road were first sampled for the current study and for Raupare, Te Waikaha and Louisa streams only limited data was available.

Dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP)

Dissolved inorganic nitrogen (DIN) concentrations measured during the current study were highly variable (Figure 3-1). Karewarewa Stream at Pakipaki, Awanui Stream at Pakipaki and Te Waikaha sites had the highest DIN levels, with concentrations at or above 1 mg/l. DIN concentrations at the remaining sites were generally low, between 0.014 mg/l and 0.231 mg/l DIN.

Comparing DIN concentrations measured during the current study with long-term SoE monitoring (for the sites where data is available) showed that the single sample result of this study was generally in the lower quartile to 25th percentile of the dataset for each respective study site, with the exception of the Karewarewa and Awanui streams at Pakipaki.

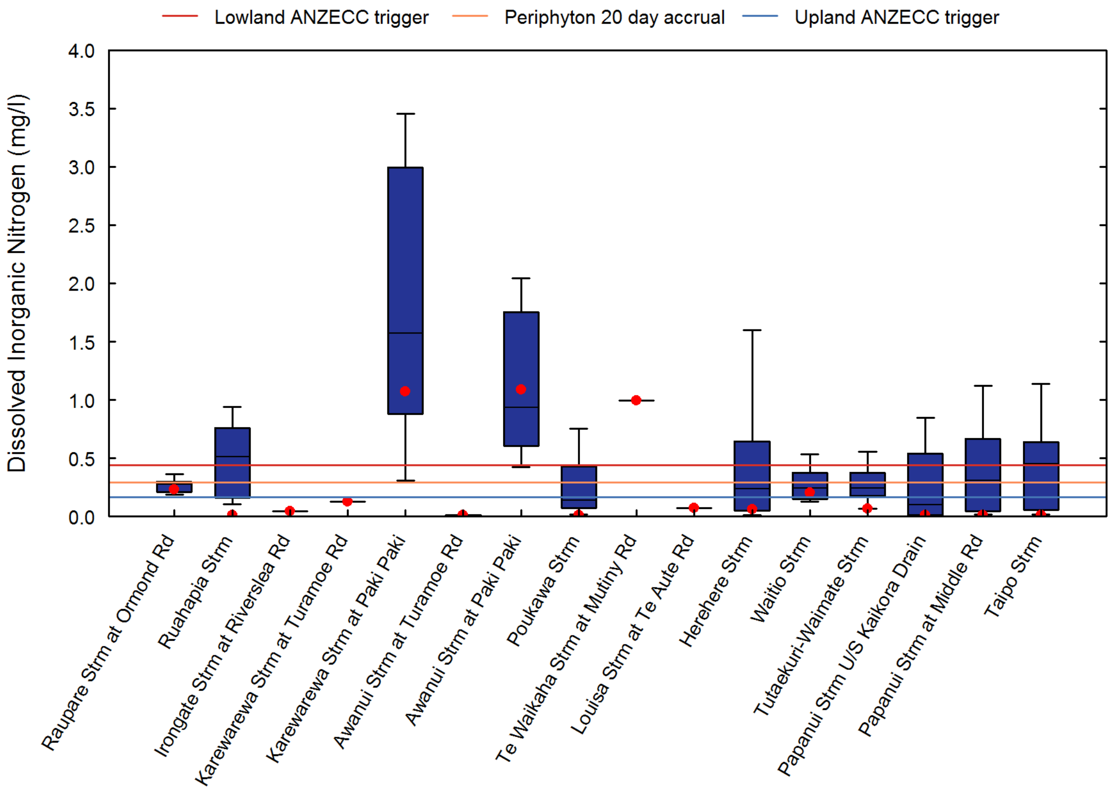


Figure 3-1: Dissolved Inorganic Nitrogen (DIN) levels for the lowland study sites. Red dots are results of the water quality sample for this study, box and whiskers are current and historic State of Environment data. Guidelines: ANZECC (2000) (top line: ANZECC lowland, bottom line: ANZECC upland) and Periphyton 20 day accrual guideline from Biggs (2000) (middle line).

During the current study streams show high dissolved reactive phosphorus (DRP) concentrations at most of the sites (Figure 3-2). ANZECC lowland trigger levels (0.01 mg/l) were exceeded at all but one stream (Ruahapia). Half of the streams had DRP levels above 0.15 mg/l and the maximum concentration measured was 0.5 mg/l DRP in the Awanui Stream at Turamoe Road.

All but three of the sites with additional data available had DRP concentrations at or above the median of the long-term concentrations observed at the sites. Only the Ruahapia, Waitio and Papanui Stream at Kaikora Drain had lower DRP concentrations than the longer-term median.

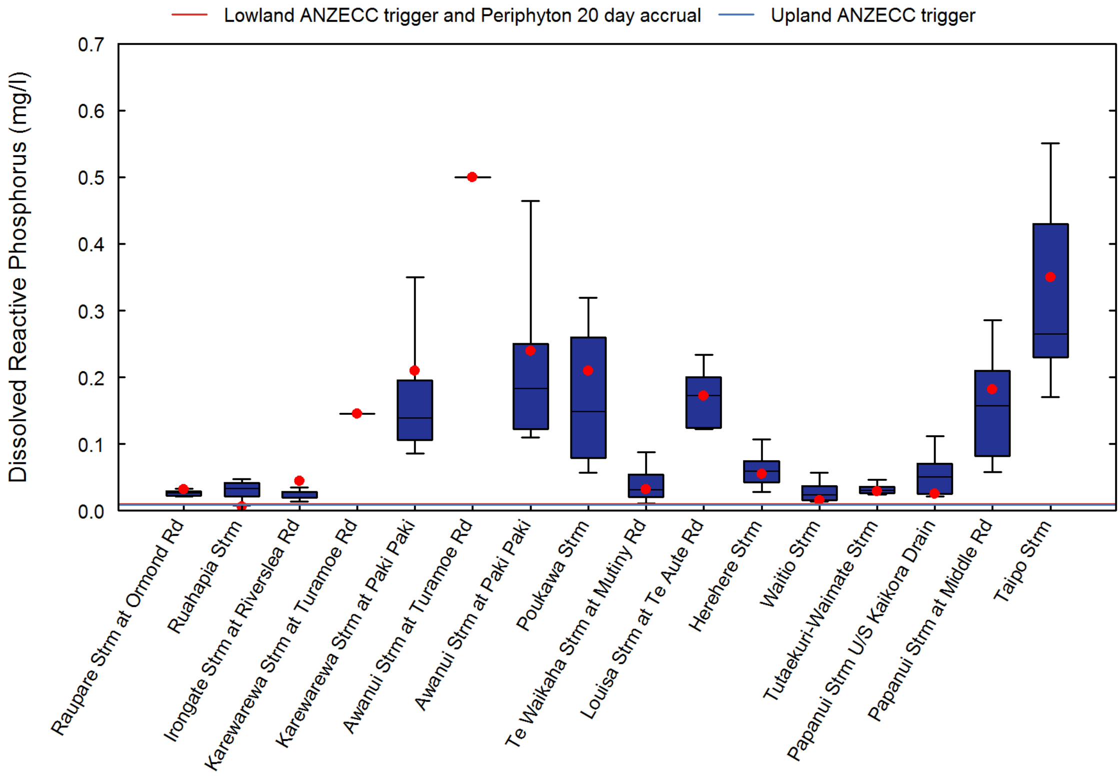


Figure 3-2: Dissolved Reactive Phosphorus (DRP) levels for the lowland study sites. Red dots are results of the water quality sample for this study, box and whiskers are current and historic State of Environment data.

Total nitrogen (TN) and total phosphorus (TP)

Figure 3-3 and Figure 3-4 are box-plots of total nitrogen and total phosphorus concentrations, respectively for the 16 sites in this study.

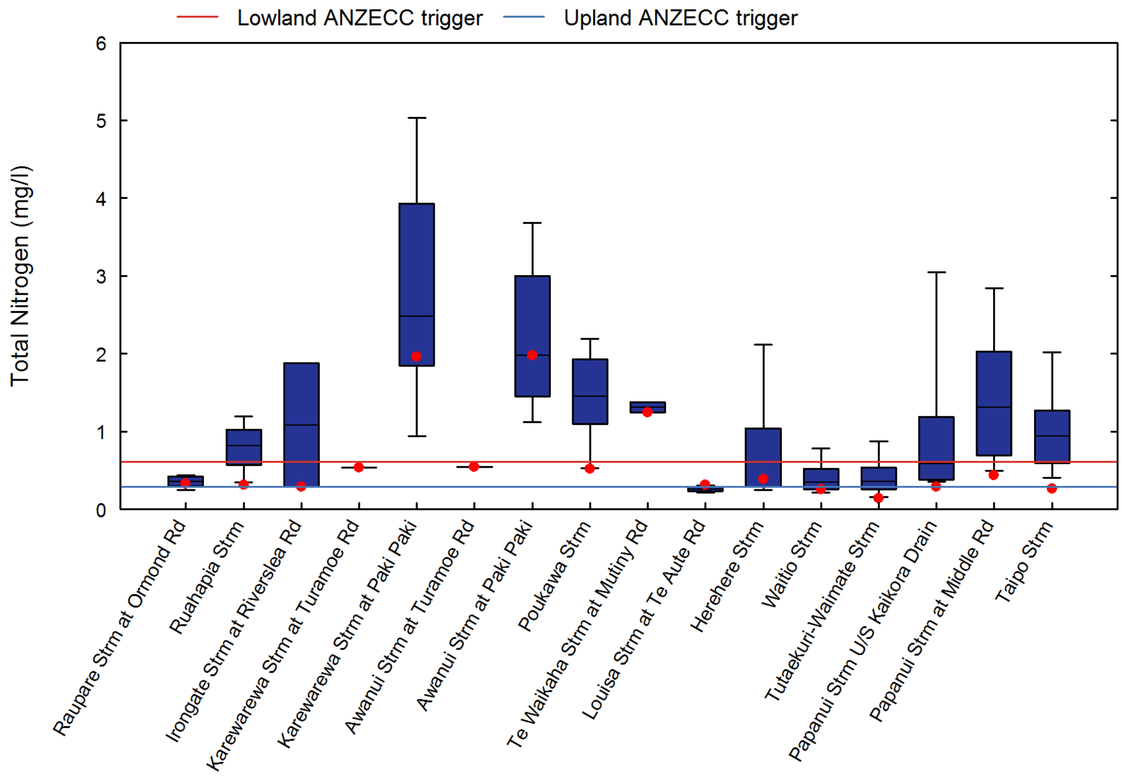


Figure 3-3: Total Nitrogen (TN) levels at the lowland stream sites. Red dots are results of the water quality sample for this study, box and whiskers are current and historic State of Environment data. Top line: lowland trigger, bottom line: upland trigger of ANZECC (2000) guidelines.

Total nitrogen levels (Figure 3-3) show a similar pattern as dissolved inorganic nitrogen levels, except at the Poukawa, the two Papanui sites and the Taipo. At these sites median total nitrogen concentrations are above the respective ANZECC trigger values, even though median DIN concentrations were below ANZECC lowland levels.

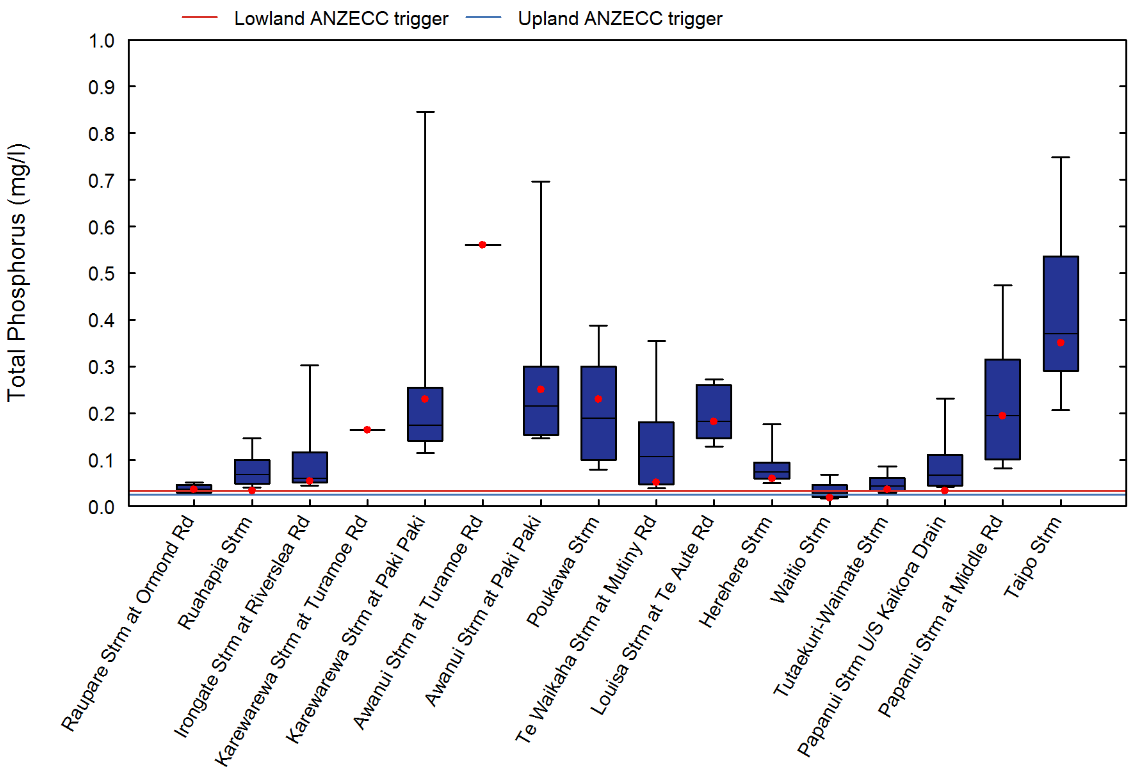


Figure 3-4: Total Phosphorus (TP) levels at the lowland stream sites. Red dots are results of the water quality sample for this study, box and whiskers are current and historic State of Environment data.

Total phosphorus concentrations show a similar pattern to dissolved reactive phosphorus. The total phosphorus (TP) samples at the study date of the Waitio Stream and Papanui upstream Kaikora Drain are below the TP lowland ANZECC trigger value, although dissolved reactive phosphorus samples for the same sites were above the DRP ANZECC trigger value.

3.2 Dissolved Oxygen, Temperature

3.2.1 Dissolved oxygen

NOTE: As in the air, oxygen dissolved in water is important for respiration of almost all aquatic organisms. Dissolved oxygen concentrations in water are controlled by several processes: The most important ones are listed below (Davies-Colley, Franklin et al. 2013):

Dissolved oxygen increases through:

(1) Re-aeration: transfer of atmospheric oxygen to water.

(2) Photosynthesis: plant and algae release oxygen during photosynthesis during daytime.

Dissolved oxygen decreases through:

(1) Respiration: Plants and algae consume oxygen from the water.

(2) Biochemical oxygen demand (BOD): microogranisms require oxygen as they consume organic matter in the water.

(3) Sediment oxygen demand (SOD): microogranisms require oxygen as they consume organic matter in the sediments.

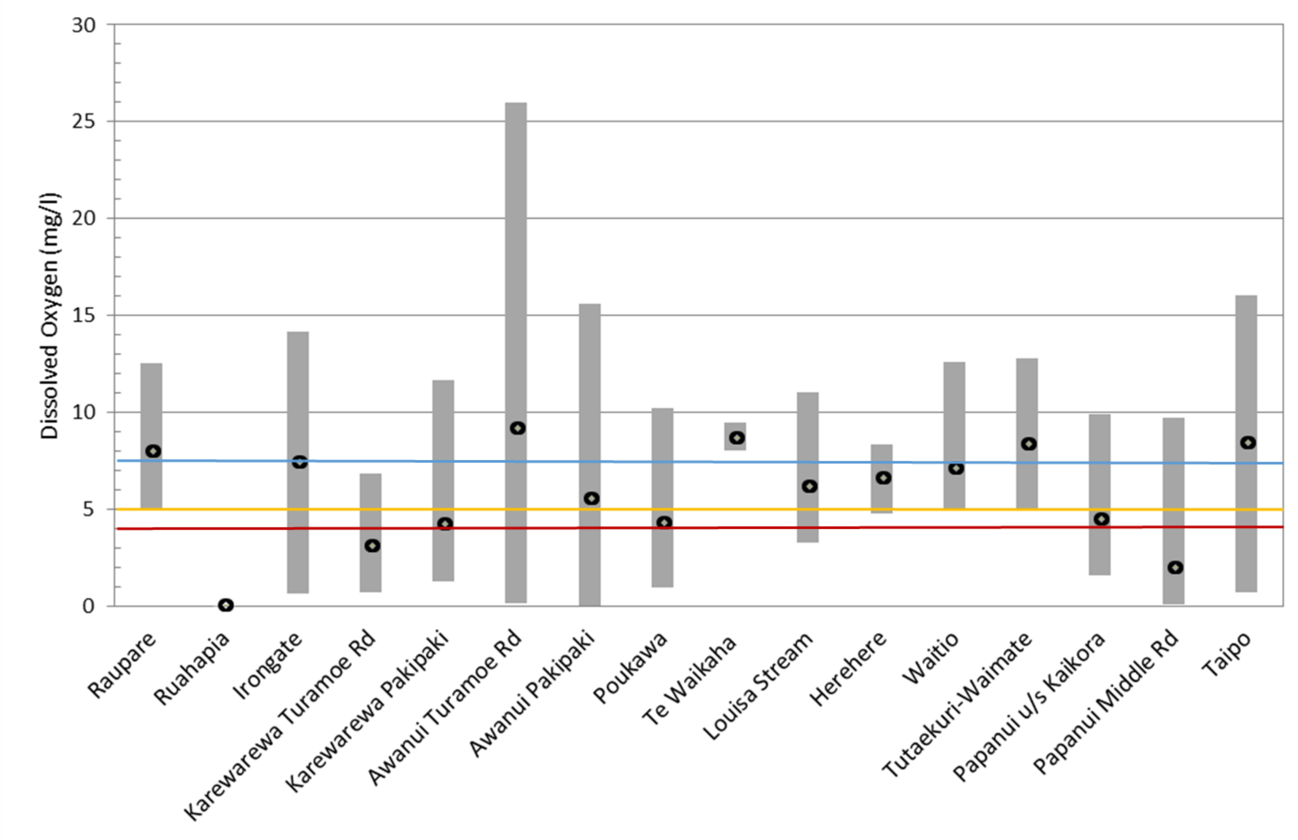


Figure 3-5: Dissolved oxygen concentration across the lowland study sites. Grey bars: 2-hour minimum to 2-hour maximum dissolved oxygen concentration from a continuous measurement over the period of logger deployment; black dots: average dissolved oxygen concentration. Lines represent proposed thresholds for ecological health ((Davies-Colley, Franklin et al. 2013) Davies-Collie et al. 2013). Above Blue line Class A: no stress caused on aquatic organisms; above orange line Class B: occasional minor stress on sensitive organisms; above red line Class C: moderate stress on a number of aquatic organisms; below red line Class D: significant, persistent stress on a range of aquatic organisms, likelihood of local extinction of keystone species and loss of ecological integrity.

Dissolved oxygen (DO) concentrations, as 2 hour moving average, decreased each day to levels of 5 mg/l or less at almost all of the study sites, except in Te Waikaha Stream. Only the sites in the Raupare, Herehere, Tutaekuri-Waimate, Waitio and Te Waikaha streams were always at or above 5 mg/l dissolved oxygen over the monitoring period. Four sites had dissolved oxygen concentrations of below 0.5 mg/l for several hours in a 24-hour period. The amplitudes between daily minimum and maximum dissolved oxygen concentrations differed considerably between sites.

The Awanui, Taipo and Irongate sites had the highest DO levels, fluctuating between <1 mg/l and >15 mg/l. Te Waikaha had the most stable DO concentrations, at around 9 mg/l, and the Ruahapia stayed close to 0 mg/l at all times. In the Ruahapia the wetted area in the stream was covered by a white mat which could have been fungus or bacteria. This site is affected by industrial discharges from the Hastings area.

A discussion paper prepared for the Ministry for the Environment (Davies-Colley, Franklin et al. 2013) suggests tentative boundaries for summer dissolved oxygen minima to protect aquatic organisms. By contrast, the currently released National Objectives Framework (NOF) bands for dissolved oxygen are set only for sites downstream of point source discharges (MfE 2014), while the dissolved oxygen threshold values for the bands are the same for rivers and streams in general in the discussion paper by (Davies-Colley, Franklin et al. 2013).

For the numeric attribute state oxygen minima are calculated either from the daily mean minimum values over 7 consecutive days within the summer period between 1 November and 30th April, or from the lowest daily minimum across the whole summer period. The Raupare and Awanui at Pakipaki sites had permanent oxygen loggers installed, which could provide continuous dissolved oxygen logger data collected over at least 7 consecutive days, as required for comparison against the NOF dissolved oxygen attribute. However at the other sites examined here, oxygen loggers were deployed for a shorter time period of only 2 to 3 days. For this reason the 1-day minimum attribute bands were used to relate to measured values in this study. This takes into account that the study period does not cover the lowest dissolved oxygen minima over the whole summer period, and that there may have been lower daily minima than measured here. The dissolved oxygen bands for the 7-day mean minimum and 1-day minimum attribute (MfE 2014) are shown in Table 3-1.

Table 3-1: Dissolved oxygen bands for ecosystem health (in DO mg/l). for the 7-day mean minimum and 1-day minimum attribute proposed in the discussion paper for the NOF (Davies-Colley, Franklin et al. (2013), MfE (2014)).

Attribute State	Numeric Attribute State		Narrative Attribute State
	7-day mean minimum (Summer Period: 1 Nov to 30th Apr)	1-day minimum (Summer Period: 1 Nov to 30th Apr)	
A	≥8.0	≥7.5	No stress caused by low dissolved oxygen on any aquatic organisms that are present at matched reference (near-pristine) sites.
B	≥7.0 and <8.0	≥5.0 and <7.5	Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance of sensitive fish and macroinvertebrate species.

Attribute State	Numeric Attribute State		Narrative Attribute State
C	≥5.0 and <7.0	≥4.0 and <5.0	Moderate stress on a number of aquatic organisms caused by dissolved oxygen levels exceeding preference levels for periods of several hours each day. Risk of sensitive fish and macroinvertebrate species being lost.
National Bottom Line	5.0	4.0	
D	<5.0	<4.0	Significant, persistent stress on a range of aquatic organisms caused by dissolved oxygen exceeding tolerance levels. Likelihood of local extinctions of keystone species and loss of ecological integrity.

Dissolved oxygen levels of 11 out of the 16 sites are in the NOF Band D, with 1-day minimum dissolved oxygen of below 4 mg/l (Figure 3-5), which indicates a significant, persistent stress on a range of aquatic organisms. when oxygen minima are calculated as a 2 hour moving average. Oxygen minima were below the 4 mg/l threshold every recorded day at the respective sites.

At sites with the most significant oxygen depletion, oxygen minima occurred typically in the early morning hours between 4:30am and 7:00am. Other streams like the Raupare, Herehere and Te Waikaha, which had minimum values of higher than 5 mg/l reach the daily minimum in the late evening between 8:00pm and 11:00pm.

Having dissolved oxygen minima occur in the late evening is unexpected, but it may indicate that the latter three streams can compensate for oxygen uptake by macrophytes at night by oxygen exchange through the river surface. By contrast, oxygen concentrations continued to drop in other streams in the early morning because there is insufficient exchange with the atmosphere through the water surface to replenish oxygen removed by plant respiration.

3.2.2 Temperature

NOTE: Temperature plays a key role in streams, because it affects instream processes such as metabolism, organic matter decomposition, and the solubility of gases. Temperature also directly affects stream biota by influencing cellular processes such as development, survival, reproductive success and behaviour.

Unlike mammals, which thermoregulate, aquatic organisms cannot keep their body at a constant temperature. Instead, their body temperature varies with that of their environment (thermoconforming). Consequently, temperature exerts a key role on physiological processes in aquatic organisms.

Thermal ranges that an organism can tolerate differ between species. There are both lethal limits, at which a species is under serious stress and eventually dies, and sub-lethal limits, that influence the feeding and growth of a species (Olsen, Tremblay et al. 2011).

The most significant instream temperature effect on aquatic organisms is summer high water temperatures.

Maximum temperature (from 2-hour moving averages) across all sites ranged between 16.6^{o}C and 27.3°C (Figure 3-6). Te Waikaha, Waitio and Tutaekuri-Waimate were the only sites at which the temperature remained below 20°C. Irongate, Karewarewa and Awanui reached maximum temperatures of above 25°C, which is also where the greatest differences were measured between maximum and minimum daily temperatures. The temperatures observed in these streams are high enough to cause stress for aquatic organisms.

The three sites with temperature maxima below 20°C also meet the Band A criteria of proposed NOF temperature regime thresholds (calculated as the Cox Rutherford Index (CRI) which is the average of daily temperature mean and maximum) (Davies-Colley, Franklin et al. 2013), indicating there is no thermal stress on any aquatic organism. The temperature regime in the Irongate falls into the proposed D-Band indicating significant thermal stress. Another 8 study sites have CRI values indicating some thermal stress potentially causing elimination of certain sensitive insect and absence of certain fish species. (Note that the index was calculated with 2-3 days data instead if 5 days data and therefore the results should be considered as indicative only.)

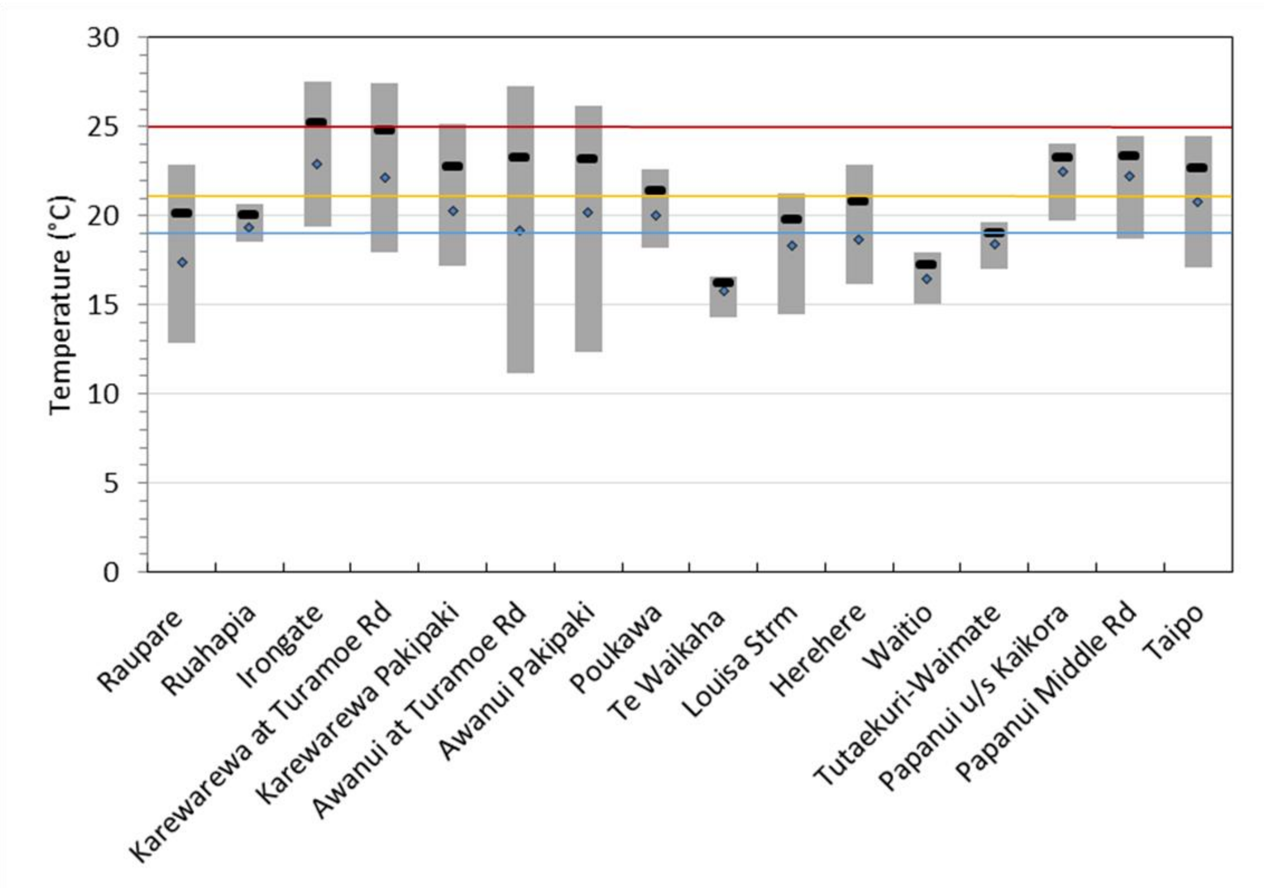


Figure 3-6: Water temperature across the lowland study sites. Grey bars: 2-hour minimum to 2-hour maximum water temperature from a continuous measurement over the period of logger deployment; squares: average water temperature; black bars: Cox-Rutherford-Index calculated as the average of the daily mean and maximum temperature. Lines represent proposed temperature regime thresholds for aquatic organisms using the Cox-Rutherford Index (Davies-Colley, Franklin et al. 2013). Below blue line Band A: no stress caused on aquatic organisms; between blue and orange line Band B: occasional minor stress on sensitive organisms; between orange and red line Band C: some occasional thermal stress, with elimination of certain sensitive insects and absence of certain fish; above red line Band D: significant thermal stress on a range of aquatic organisms. Risk of local elimination of keystone species with loss of ecological integrity.

3.3 Ecosystem Metabolism

NOTE: Ecosystem metabolism is a measure of the balance between primary production, which is organic carbon and oxygen production through photosynthesis, and respiration, which consumes organic carbon and oxygen through breakdown of organic matter.

In some situations ecosystem metabolism may be primarily based on instream production by aquatic plants and algae. It may also be based on breakdown of terrestrial organic matter. If rates of carbon production equal or exceed rates of carbon consumption, the food chain depends on instream production. Where carbon consumption exceeds production, instream processes are dominated by terrestrial inputs of organic matter from the catchment. The nature of ecosystem metabolism provides information on the food base in a stream and on ecosystem health, and helps to determine instream life-supporting capacity (Young, Townsend et al. 2004) (Young, Matthaei et al. 2008).

High rates of ecosystem respiration and primary production cause extreme daily fluctuations in dissolved oxygen concentrations in some of the streams. Re-aeration or the physical exchange (diffusion) of atmospheric oxygen through the water surface can help to offset oxygen 'sags' caused by stream respiration. However, deeply-incised, narrow, uniform channels with slow flow and low levels of water turbulence reduce the exchange between atmospheric air and water, limiting instream reaeration. This type of channel morphology is typical of the study sites.

At sites in the Ruahapia Stream at the Showgrounds and Te Waikaha Stream at Mutiny Road daily metabolism results did not achieve an $R^2 > 0.4$. Both streams demonstrated low amplitude changes in dissolved oxygen. Te Waikaha Stream dissolved oxygen ranged between 80.2% and 98% and 7.9 mg/l and 9.6 mg/l, with short term fluctuations, and Ruahapia stream dissolved oxygen ranged between 0% and 0.27% and 0 mg/l and 0.025 mg/l.

Observations were repeated at both sites using a different logger, but the range of dissolved oxygen concentrations and the pattern of fluctuation stayed the same. A repeat measurement was also undertaken at the Awanui Stream at Turamoe site, where dissolved oxygen concentrations exceeded 20 mg/l. Although the repeat measurement was recorded during overcast conditions, which would be expected to depress plant respiration, the dissolved oxygen concentration nonetheless reached 19 mg/l.

Because of the missing metabolism values for Te Waikaha and Ruahapia streams, the NMDS analysis with all 16 sites was performed without metabolism variables. To test the correlation with metabolism variables ecosystem respiration, primary production and P/R ratio, a reduced analysis with 14 sites (excluding Te Waikaha and Ruahapia) was performed, but the Spearman Rank Correlation for these variables was low (ecosystem respiration < 0.3, primary production < 4 and P/R < 5). Therefore the full 16-site NMDS analysis was included in this report.

Figure 3-7 shows metabolism rates in gross primary production (GPP) and ecosystem respiration (ER) as gO_2/m^2/day, and thresholds suggested by Young, Townsend et al. (2006) for satisfactory health as shown in Table 3-2. No metabolism/respiration results could be calculated for the Te Waikaha and Ruahapia, as explained in Section 2.4.3.

Table 3-2: Suggested criteria for metabolism thresholds from (Young, Townsend et al. 2006).

Parameter	**Threshold** ($gO_2/m^2/day$)	**Category**
Gross Primary Production GPP ($gO_2/m^2/day$)	GPP < 4.0 GPP = 4.0 – 8.0 GPP > 8.0	Healthy Satisfactory Poor
Ecosystem Respiration ER ($gO_2/m^2/day$)	ER > 10 ER = 5.5 – 10 ER = 1.5 – 5.5 ER = 0.7 – 1.5 ER < 0.7	Poor Satisfactory Healthy Satisfactory Poor

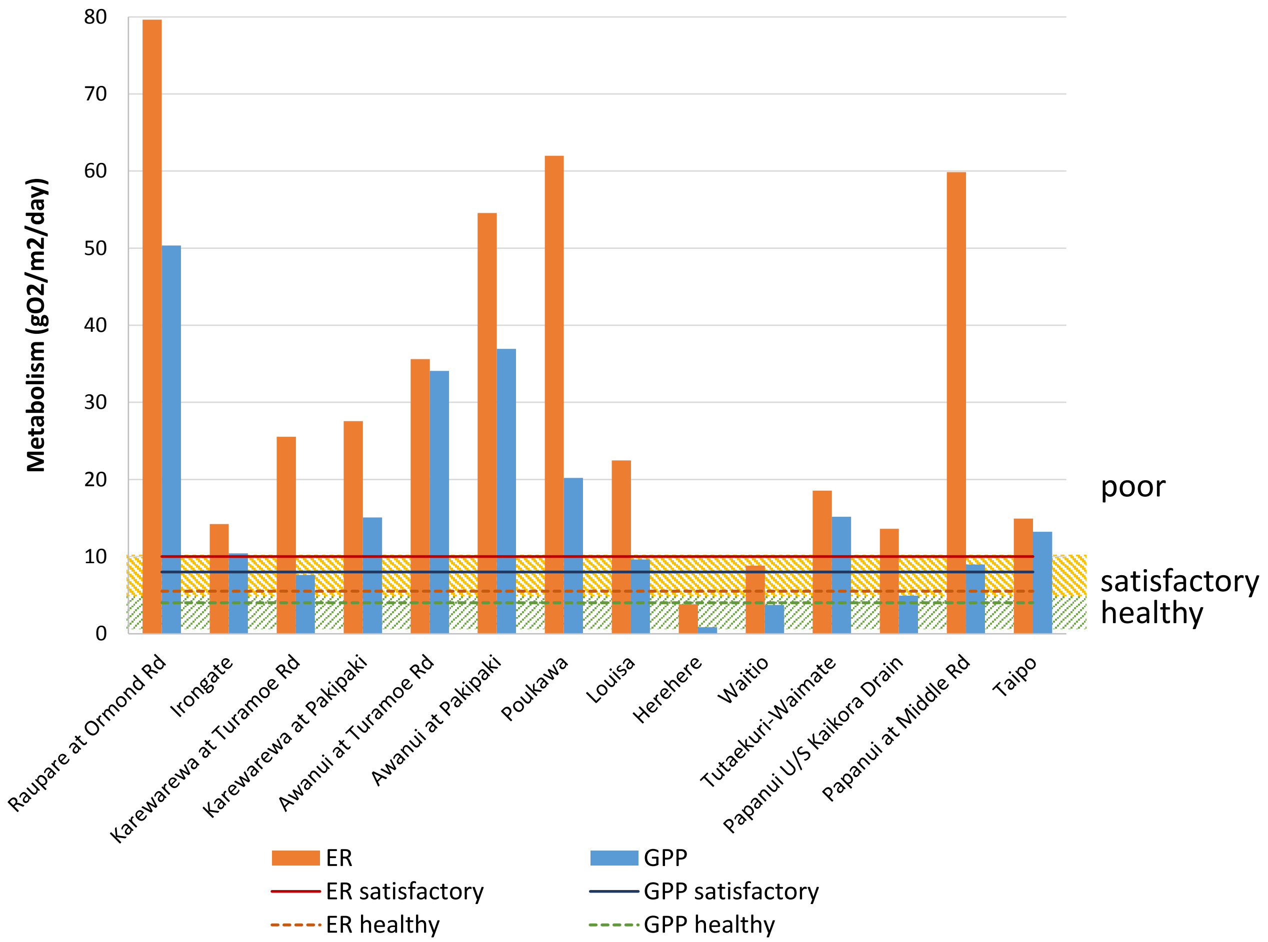


Figure 3-7: Rates of gross primary production (GPP) and ecosystem respiration (ER) at the study sites. The thresholds between 'poor' and 'satisfactory' conditions are 8 g O_2/m^2/day for GPP (blue line), and 10 g O_2/m^2/day for ER (red line), thresholds between satisfactory and healthy conditions are 4 O_2/m^2/day for GPP (green dashed line) and 5.5 O_2/m^2/day for ER (orange dashed line). Thresholds for ER <0.7 O_2/m^2/day (poor) and 0.7 – 1.5 O_2/m^2/day (satisfactory) not shown as the lowest ER value in this dataset was 3.8 O_2/m^2/day.

Ecosystem Metabolism rates for GPP ranged from 0.89 gO_2/m^2/day in the Herehere Stream to 50.3 gO_2/m^2/day in the Raupare at Ormond Road. Karewarewa at Turamoe Rd, Papanui upstream of (U/S) Kaikora Drain, Herehere and Waitio are the only 4 sites that fall into the criteria suggested for satisfactory to healthy condition for GPP, with values below 8 gO_2/m^2/d.

Rates of ER ranged from 3.83 gO_2/m^2/d to 79.6 gO_2/m^2/d, and oxygen uptake by respiration was always higher than oxygen increase by primary production. More than half of the sites have particularly high ER rates of greater than 20 gO_2/m^2/day. The balance between GPP and ER, known as Productivity/Respiration (P/R) was below a ratio of 1 at all sites, indicating that respiration exceeded production at all sites. The metabolism in these streams is driven primarily driven by the breakdown of organic matter. This organic material probably derives from upstream or the surrounding land area.

Only the sites at Herehere Stream and Waitio Stream indicated 'satisfactory' or 'healthy' conditions for both indicators of metabolism, with GPP and ER values within these ranges of < 8 gO_2/m^2/day and < 10 gO_2/m^2/day respectively.

3.4 Aquatic plants

NOTE: Macrophytes typically grow in low gradient, slow flowing, fine bed substrate lowland streams and rivers, and can reach nuisance levels in summer, when growth rates peak. In high abundance macrophytes can have a detrimental effect on ecological health by impacting instream dissolved oxygen levels through photosynthetic processes, by reducing flow conveyance, and by detrimentally affecting aesthetic and recreational values. In addition, consumption of inorganic carbon during photosynthesis results in changes to the equilibrium balance of carbonate/bi-carbonate/carbonic ions and can lead to marked diurnal fluctuations in pH.

There are currently no national guidelines in New Zealand for nuisance macrophyte abundance in streams or rivers. Provisional guidelines are suggested as ≤ 50% cover for the cross-sectional area/volume (CAV) with the purpose of protecting ecological conditions, flow conveyance and recreation, and ≤ 50% surface area (SA) for aesthetics and recreation (Matheson, Quinn et al. 2012). Matheson, Quinn et al. (2012) stress that only sparse information exists on the relationship between instream macrophyte abundance and detrimental impacts on key instream values, and further research is needed.

More information is needed on the relationship between instream macrophyte abundance and dissolved oxygen and pH conditions, and the relationship between macrophyte abundance and macroinvertebrate communities. This information will help determine thresholds for the maintenance of instream ecological health values.

Macrophyte abundance was assessed by quantifying the proportion of water surface area covered and the proportion of cross-sectional area/volume occupied in the stream channel.

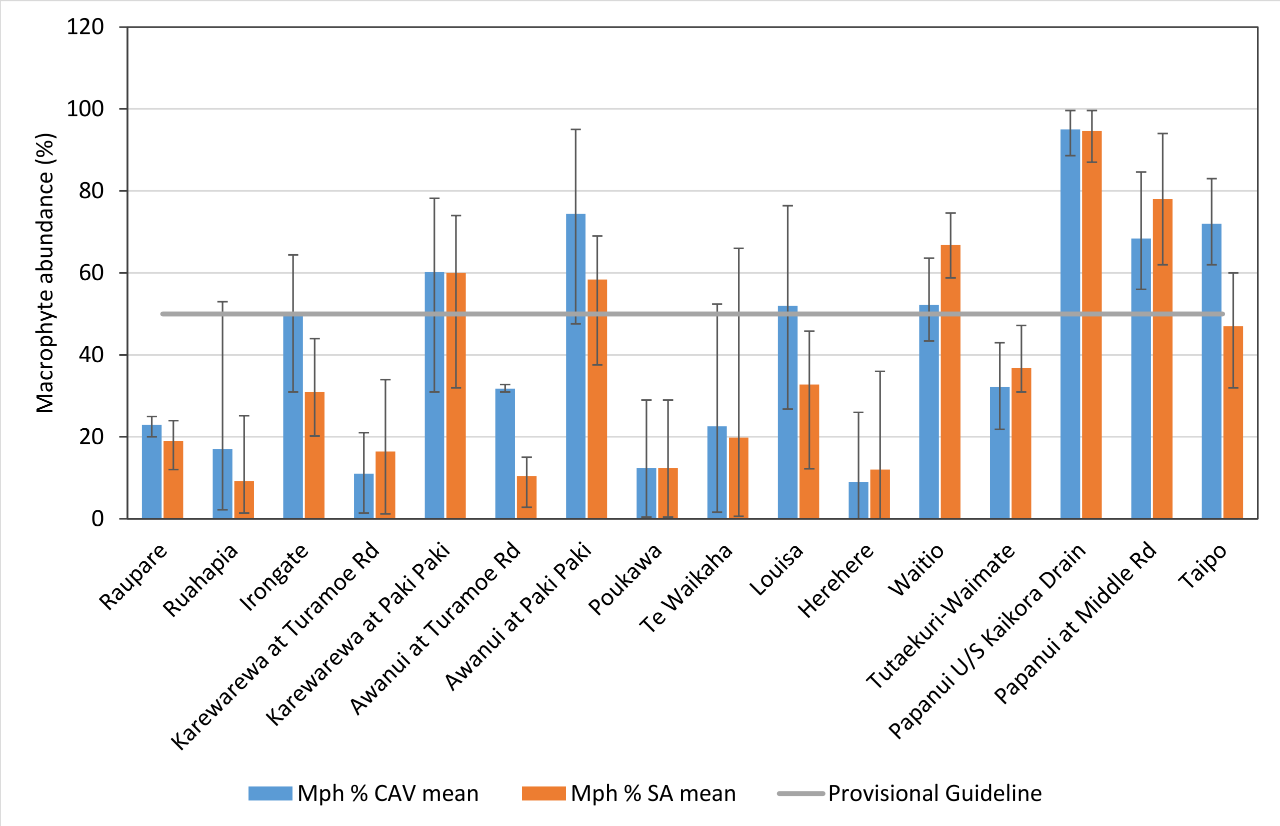


Figure 3-8: Percent macrophyte abundance at the study sites. Mph% CAV means proportion cover of stream channel cross-section area and volume. Mph% SA means proportion cover of surface area across the stream channel. Grey line: Provisional Macrophyte guideline (Matheson, Quinn et al. 2012).

Macrophyte abundance was variable between transects at most sites, with differences between maximum and minimum abundance of around 50% measured both as CAV and as SA. For example, CAV ranged between 0% and 55% at Te Waikaha Stream, and between 26% and 80% at Louisa Stream. Cross-section area/volume and surface area plant abundance were correlated, which indicates that surface reaching and emergent plants were dominant, rather than floating-leaf plants, which tend only to cover the surface but not the cross-section of the channel.

The Irongate stream was at the provisional guideline for CAV of 50% to protect ecological conditions, flow conveyance and recreation. The guideline was exceeded in the Karewarewa at Pakipaki, Awanui at Pakipaki, Louisa, Waitio, at both sites in the Papanui, and in the Taipo.

The guideline of 50% SA for recreation and aesthetical values was exceeded in the Karewarewa at Pakipaki, Awanui at Pakipaki, Waitio, and at both Papanui sites.

More than 20 different aquatic plants were identified during this survey (Table 3-3). Submerged macrophytes like the Canadian pondweed (*Elodea canadensis)* and the curled pondweed (*Potamogenton crispus*), as well as the emergent water celery (*Apium nodiflorum*) were the most prevalent species at up to 10 out of 16 sites. However, plant composition differed from site to site since most of the other macrophytes were only present at 1 or 2 of the 16 sites. The sites in the Papanui and the Awanui were the most diverse in terms of aquatic plants identified.

Table 3-3: Macrophytes present at the study sites. Native macrophyte species in bold. Growth form: E: Emergent; F: Floating; S: Submerged.

	Apium nodiflorum	*Azolla* sp.	*Callitrice stagnalis*	*Ceratophyllum demersum*	*Egeria densa*	*Elodea canadensis*	*Glyceria maxima*	*Isolepsis*	*Juncus* sp.	*Lemna*	*Myriophyllum aquaticum*	*Myriophyllum* sp.	***Myriophyllum triphyllum***	*Nasturtium officinale*	*Persicaria hydropiper*	*Persicaria* sp.	*Potamogeton crispus*	***Potamogeton ochreatus***	*Potamogeton* sp.	*Ranunculus trichophyllus*	*Moss*	*other grass spp.*	*Algae: green filamentous*	*Charophyta*
Habitus	*E*	*F*	*S*	*S*	*S*	*S*	*E*	*E*	*E*	*F*	*E*	*/*	*S*	*E*	*E*	*E*	*S*	*S*	*/*	*S*	*S*	*E*	*S*	*S*
Raupare	X					X											X							
Ruahapia								X	X						X				X	X		X		
Irongate						X														X				
Karewarewa at Turamoe Rd						X						X		X						X			X	
Karewarewa at Paki Paki	X												X				X			X		X		
Awanui at Turamoe Rd	X					X				X				X			X						X	
Awanui at Paki Paki	X	X				X	X				X			X						X				
Poukawa														X		X	X							
Te Waikaha			X												X		X				X		X	X
Louisa	X	X		X		X																		
Herehere	X																						X	
Waitio	X					X														X			X	
Tutaekuri-Waimate				X		X											X			X			X	X
Papanui U/S Kaikora Drain	X					X			X				X	X	X								X	
Papanui at Middle Rd	X					X							X	X	X		X	X						
Taipo					X									X			X							

Two native aquatic plant species were present: *Potamogeton ochreatus* in the Papanui at Middle Road and *Myriophyllum triphyllum* in the Karewarewa at Pakipaki and at both sites in the Papanui.

Green filamentous algae were often growing as epiphytes smothering the macrophytes, except for in the Herehere, where it was growing on hard substrate in the centre of the channel which was free of submerged macrophytes (emergent *Apium nodiflorum* was present at the channel margins within the sampling reach). Generally periphyton or algae cover was low with all sites being dominated by aquatic macrophyte cover as opposed to algal cover.

3.5 Habitat Assessment

Overall, stream bank stability of both banks was good at most of the stream sites, scoring higher than 10 points as an average of right and left stream bank stability at all sites except the Herehere, Irongate and Raupare streams.

Invertebrate habitat and riparian shade were the two poorest categories across the sites. 10 of the 16 sites had only rare or no suitable habitat for aquatic invertebrates in the orders Ephemeroptera (Mayflies), Plecoptera (Stoneflies), Trichoptera (Caddisflies), known collectively as EPT taxa. 11 of the 16 sites had less than 10% shading of the wetted width at baseflow.

Overall Te Waikaha, Papanui, Herehere, Waitio and Tutaekuri-Waimate sites had the highest scores of around 100 points to 140 points. Te Waikaha, the highest scoring site, provided most habitat for EPT taxa and fish, had stable stream banks and, although the riparian buffer width was low, provided high shading for the stream with mature trees.

Lower scoring sites with less than 60 points did not provide suitable habitat for EPT taxa or fish. They also were devoid of riparian vegetation, or a functioning buffer strip and shade for the stream channel. The only high scores amongst these sites occurred where stable stream banks existed at the Karewarewa, Awanui at Pakipaki, and Poukawa.

Table 3-4: Scores for habitat assessment across the lowland stream study sites. Scores between 1 (lowest habitat value) and 20 (highest habitat values) given for each habitat category. Bank stability, bank vegetation and riparian buffer width are calculated as an average between left and right bank value. *Fine sediment was excluded from the calculation of the overall habitat score.

	*Fine sediment deposition**	Invertebrate habitat	Fish cover	Hydraulic heterogeneity	Bank stability avg	Bank vegetation avg	Riparian buffer (width) avg	Riparian shade	Channel alteration	Habitat score
Raupare	*1*	1	5	11	8	4	6	1	1	43
Ruahapia	*1*	1	11	1	12	7	11.5	12	13	80.5
Irongate	*8*	5	6	5	4.5	4	8	2	13	58.5
Karewarewa at Turamoe Rd	*1*	3	5	5	12	7	12	1	10	63
Karewarewa at Pakipaki	*1*	8	3	3	17	5	5	3	3	58
Awanui at Turamoe Rd	*1*	3	5	3	11	4	4	1	5	44
Awanui at Pakipaki	*1*	3	6	5	16	5	5	1	2	52
Poukawa	*1*	4	3	1	17	5	6	2	5	50
Te Waikaha	*9*	15	16	19	17.5	8.5	7	16	11	141
Louisa	*1*	1	8	6	12	9	7.5	15	13	80.5
Herehere	*10*	12	12	16	8.5	8	6.5	16	10	113
Waitio	*16*	15	7	8	18	8	8	1	15	102
Tutaekuri-Waimate	*16*	11	16	10	16	4.5	9	2	3	98.5
Papanui U/S Kaikora Drain	*17*	12	13	8	16	7	9	2	9	101
Papanui at Middle Rd	*10*	18	12	11	14	9	5	9	16	124
Taipo	*1*	2	10	2	11	1	5	1	1	45

3.6 Macroinvertebrate communities

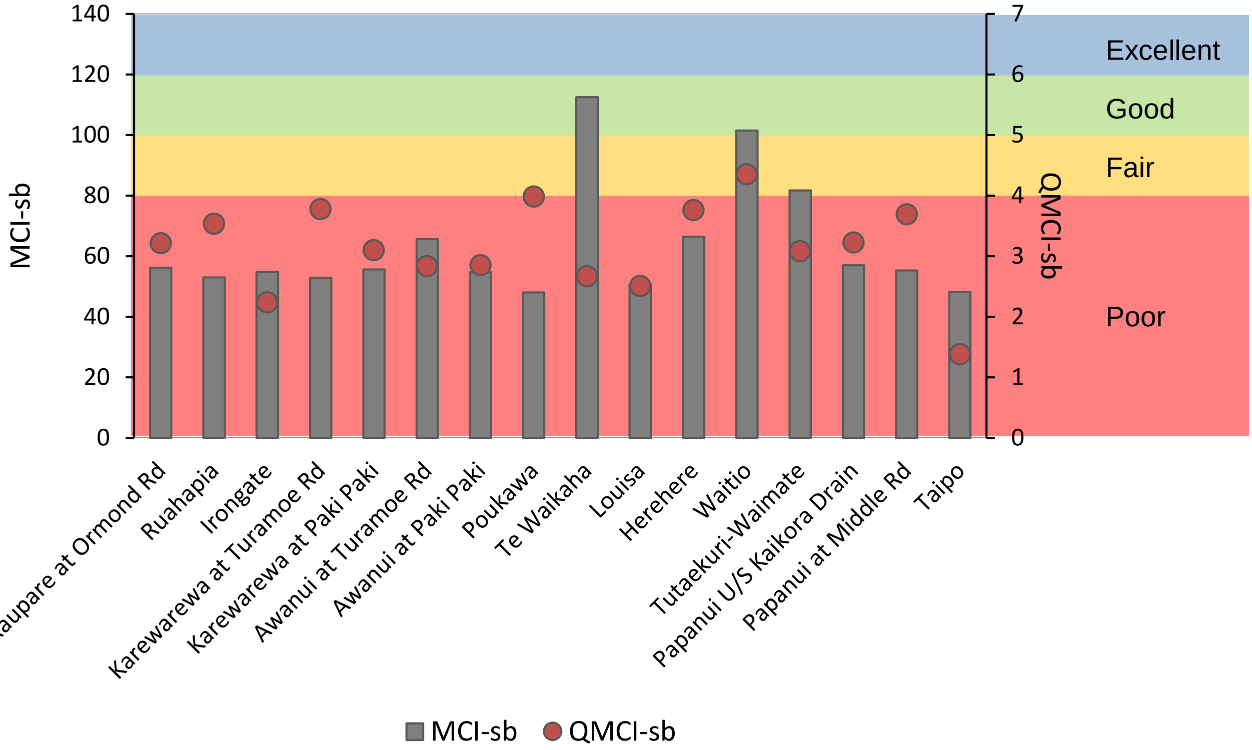


Figure 3-9: MCI-sb and QMCI-sb scores across the lowland stream study sites.

59 MCI-level taxa were found across all study sites, of which 16 belong to EPT orders. On average, 20 taxa were found at each site, ranging from a maximum of 35 taxa in the Tutaekuri-Waimate, to a minimum of 8 taxa in the Ruahapia.

The generally more sensitive Plecoptera (stoneflies) were not present at any of the sites. The highest diversity in EPT taxa was found in the Tutekuri-Waimate, Waitio and Te Waikaha streams, where between 8 and 12 different Trichoptera and Ephemeroptera taxa were found. By contrast, the Herehere Stream had only 2 EPT taxa, however they were the more pollution sensitive Hudsonema (Trichoptera) and Zephlebia (Ephemeroptera). At all other sites with EPT taxa present, only the pollution tolerant Hydroptilidae Oxyethira and/or Paraoxyethira where found. The Taipo, Ruahapia and Awanui Stream at Turamoe Rd had no EPT taxa at all.

13 out of the 16 study sites showed poor MCI-sb values of lower than 80, with the lowest MCI-sb being less than 60 in the Ruahapia Stream and the Taipo Stream, indicating severe degradation. MCI-sb in the Tutaekuri-Waimate indicated fair water quality and Te Waikaha and Waitio had MCI values of 112 and 101 respectively, indicating good water quality (Figure 3-9, Table 3-5). All sites except for 2 (Waitio and Poukawa) show poor QMCI-sb values of lower than 4.

The Waitio ranked highly in the QMCI-sb and MCI-sb because of two high scoring EPT taxa. Deleatidium was found at densities of more than 500 individuals/m^2, and Olinga more than 400 individuals/m^2, and almost

60% of all individuals were EPT taxa at this site. In contrast to this Te Waikaha had a high MCI-sb score because 40% of the taxa found at the site belonged to the EPT taxon group, but the occurrence of two low scoring taxa in mass abundance lowered the score of the quantitative QMCI-sb.

In the Ruahapia, the most abundant taxa were Chironomus (>1500 individuals/m^2) and Oligochaeta (>700 individuals/m^2). The Ruahapia Stream site is influenced by discharges from the Hastings industrial area.

Table 3-5: Macroinvertebrate indices across sample sites. Taxa richness: number of taxa found at the site; Abundance: total number of macroinvertebrate individuals; sb: soft bottom.

	Taxa richness	Total abund.	EPT taxa richness	EPT abund.	% EPT taxa	% EPT abund.	MCI	QMCI	MCI-sb	QMCI-sb
Raupare at Ormond Rd	24	32797	2	514	8.3	1.6	65.8	4.2	55.8	3.0
Ruahapia	8	2371	0	0	0.0	0.0	57.5	1.2	53.0	3.5
Irongate	18	12757	2	133	11.1	1.0	63.3	3.6	54.2	2.2
Karewarewa at Turamoe Rd	20	12832	1	19	5.0	0.1	69.0	4.5	52.4	3.5
Karewarewa at Pakipaki	18	23300	2	1991	11.1	8.5	68.9	4.1	55.1	3.0
Awanui at Turamoe Rd	20	1914	0	0	0.0	0.0	74.0	3.4	65.1	2.8
Awanui at Pakipaki	24	14471	2	568	8.3	3.9	73.3	4.1	54.3	2.7
Poukawa	16	9960	1	6	6.3	0.1	63.8	4.5	47.4	3.7
Te Waikaha	20	21073	8	954	40.0	4.5	112.0	4.3	106.5	2.6
Louisa	12	8327	1	6	8.3	0.1	61.7	3.9	49.8	2.4
Herehere	13	11079	2	17	15.4	0.2	75.4	4.5	65.7	3.5
Waitio	23	5971	11	3518	47.8	58.9	100.9	5.2	101.0	4.3
Tutaekuri-Waimate	35	9432	12	763	34.3	8.1	88.6	3.6	81.7	3.0
Papanui U/S Kaikora Drain	21	25952	2	260	9.5	1.0	64.8	4.1	55.6	3.1
Papanui at Middle Rd	19	10996	2	947	10.5	8.6	62.1	4.0	53.7	3.5
Taipo	11	805	0	0	0.0	0.0	56.4	3.1	48.2	1.4

3.7 Relationships between environmental variables and macroinvertebrate community composition

NOTE: The macroinvertebrate community is the most diverse animal assemblage in streams, consisting of taxa that need different instream habitats, and physical and chemical conditions. Macroinvertebrate community compositions change in response to a wide array of environmental factors present at a site. Pristine conditions offer life supporting capacity to sensitive species adapted to specific niches, as well as to generalist taxa. At sites where environmental conditions are affected, sensitive species are found less frequently or are absent from an invertebrate community, leaving an assemblage that is dominated by tolerant taxa.

Statistical techniques can be used to examine the relationships between taxonomic composition and environmental gradients, and to help identify the main causes of community changes. The objective here was to identify the environmental conditions that best explained the variation in the macroinvertebrate community in the macrophyte dominated lowland streams in the Heretaunga plains. The study also sought to explain low MCI scores at some of the sites.

A cluster analysis was first performed, to identify any similarities and differences between the taxonomic compositions at the 16 sites. Then a multivariate analysis (NMDS) was them performed to find the strongest relationship between environmental variables that may act as potential stressors and taxonomic composition.

The cluster analysis produced 4 groups of sites characterised by similar macroinvertebrate communities and one single site different to any other group (Figure 3-10). The largest group with similar taxonomic composition consists of the sites in the Papanui, Awanui, Karewarewa, Irongate and Raupare streams, all of which have a pollution tolerant macroinvertebrate community with an MCI-sb of generally below 60. At these sites a maximum of 2 EPT taxa were present which are the pollution tolerant Trichoptera: Oxyethira and Paraoxyethira. The second group (Herehere, Louisa and Poukawa streams) has overall fewer taxa than the previous group, but a similar composition in the remaining taxa. Ruahapia and Taipo streams have the lowest taxon richness of these study sites with only 8 and 11 pollution tolerant taxa found at the sites respectively. The taxon with the highest MCI-sb score found at these sites is Oligochaeta with a score of 3.8. The remaining group of two the sites Te Waikaha and Waitio, and the single site Tutaekuri-Waimate have the highest EPT taxa richness compared to the other groups, and the highest MCI-sb scores. The Tutaekuri-Waimate has the highest overall taxa richness (35 taxa whereas the other sites have a maximum of 25 taxa, and an average of less than 20). The map in Figure 3-10 shows that the sites grouped together statistically based on their similarity in macroinvertebrate composition have no particular spatial pattern. Representatives of each group are spread out across the study area. Even the largest group (green triangles), that seem to cluster around Pakipaki in the centre of the Karamu catchment, has sites of similar community composition at the north boundary of the Karamu catchment and two sites outside of the Karamu catchment (Papanui sites in the Tukituki catchment).

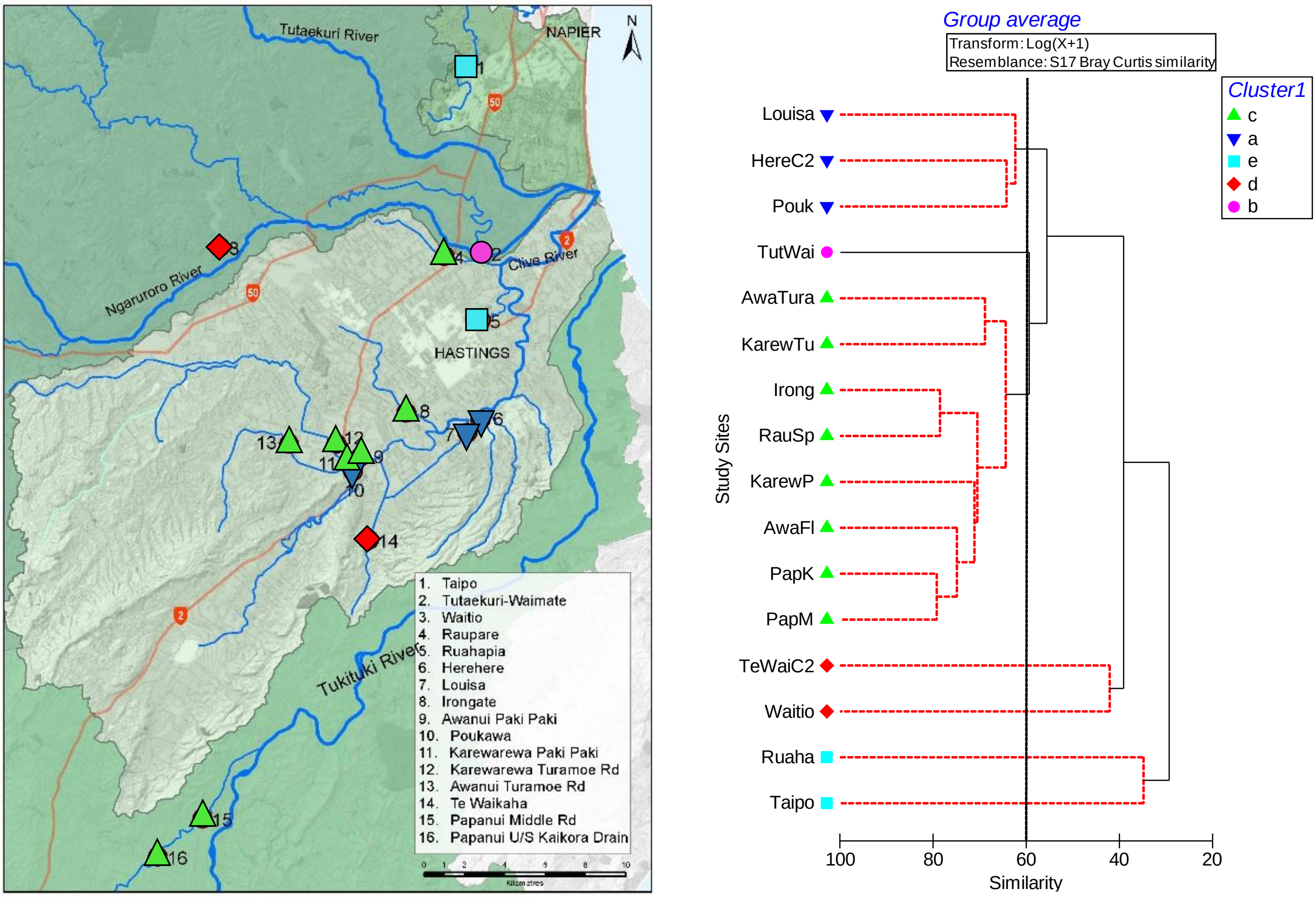
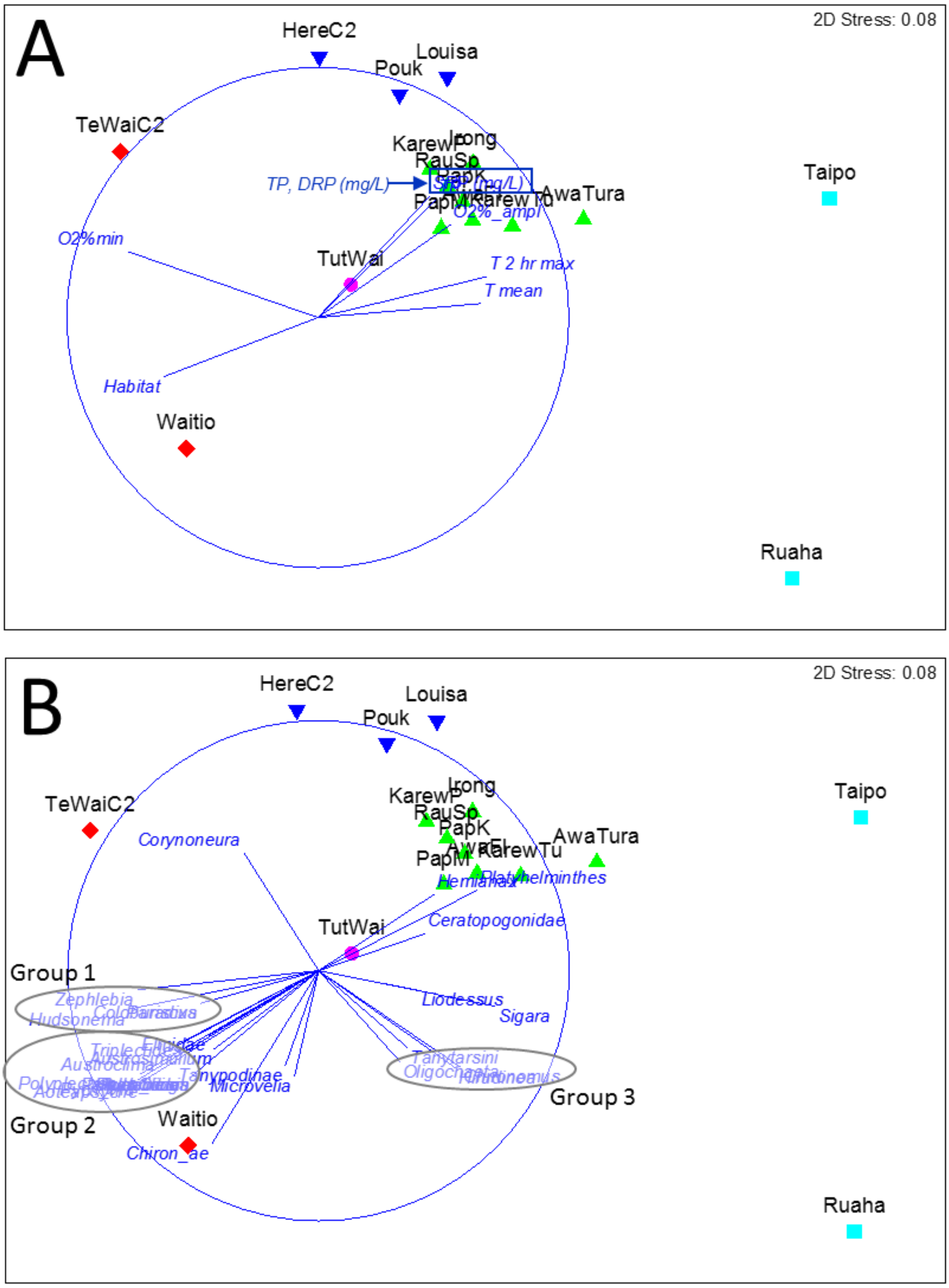


Figure 3-10: Cluster analysis for similarity of the study sites using the macroinvertebrate community. Cluster groups shown at > 60% resemblance. Red lines indicate no significant difference between sites (= genuine clusters) (SIMPROF permutation test with 999 permutations, p<0.05).

The relationship between environmental variable distributions and changes in macroinvertebrate community composition across the study sites can be seen in Figure 3-11. The main environmental gradients (lines pointing in the direction of increasing values) correlated with a change in macroinvertebrate community composition across the study sites (symbols) were: 1. Habitat score, 2. Oxygen concentration, 3. Water temperature and 4. Instream phosphorus concentration (Figure 3-11A). The other nine environmental variables that were analysed but are not shown in the diagram were correlated only weakly with the macroinvertebrate community composition (Spearman correlation of less than 0.6).

Figure 3-11 shows that the taxonomic composition at the sites Te Waikaha, Waitio, and Tutaekuri-Waimate relates to higher habitat scores, higher oxygen minima (less severe oxygen depletion at night and less extreme fluctuation in oxygen concentration), and lower temperatures (maxima and average, as indicated by the line for temperature increase which is pointing in the opposite direction of the sites). At these three sites mayflies (Ephemeroptera) and caddisflies (Trichoptera) are more abundant than at any other sites, e.g. the Ephemeroptera Austroclima, Coloburiscus, Deleatidium and Zephlebia and the Trichoptera Hudsonema, Aoteapsyche, Olinga, Polyplectropus, Psilochorema and Pycnocentria. Worms and molluscs are less abundant and or absent at these sites (Figure 3-11B).



Group 1	Group 2	Group 2 cont.	Group 3
Zephlebia	*Elmidae*	***Polyplectropus***	*Tanytarsini*
Coloburiscus	***Triplectides***	***Aoteapsyche***	*Oligochaeta*
Paradixa	*Austrosimulium*	***Pycnocentria***	*Hirudinea*
Hudsonema	***Austroclima***	***Hydrobiosis***	*Chironomus*
		Olinga	
		Psilochorema	
		Pycnocentrodes	
		Deleatidium	

Figure 3-11: Two dimensional non-metric multidimensional scaling plot (axis 1 and 2) of macroinvertebrate community composition. A. environmental variables (shown for Spearman rank correlation >0.6). B. macroinvertebrate taxa (shown for Spearman rank correlation >0.6). Symbols represent study site groups based on

hierarchical clusteringFigure 3-10: Cluster analysis for similarity of the study sites using the macroinvertebrate community. (Figure 3-10). Taxa shown in bold belong to the orders Trichoptera and Ephemeroptera.

Sites located in the other areas in the ordination space have higher temperature maxima, lower dissolved oxygen minima and low habitat scores, as well as high DRP concentrations. These sites are characterised by high abundances in worms, snails, crustaceans and midges. Caddisflies and mayflies are largely absent.

Taxa with higher MCI scores were more abundant at the sites with lower temperature maxima, higher oxygen minima and better habitat (Te Waikaha, Tutaekuri-Waimate and Waitio). These taxa included caddisflies including Polyplectropus (MCI tolerance value (TV) 8), Psilochorema (MCI TV 8) and Pycnocentria (MCI TV 7); and mayflies including Austroclima (MCI TV 9), Coloburiscus (MCI TV 9), Deleatidium (MCI TV 8) and Zephlebia (MCI TV 7).

On the other side of the diagram are sites with high water temperature, low dissolved oxygen, low habitat scores and high DRP concentrations. These sites have high abundances of pollution tolerant taxa with low MCI TV scores such as worms, snails and midges like Platyhelmithes (MCI TV 3), Oligochaeta (MCI TV 1) and Ceratopogonidae (MCI TV 3). The two caddisfly species that are pollution tolerant (and are also the only low-scoring MCI taxa within the EPT group) - Hydroptilidae Oxyethira (MCI TV 2) and Paroxyethira (MCI TV 2) - also increase in numbers at these sites, particularly in the Awanui, Papanui, Karewarewa streams at the lower, downstream sites.

3.8 Correlations between macroinvertebrate metrics and stressors

Temperature maximum, dissolved oxygen minimum and habitat - the variables strongly associated with changes in the community composition - were correlated with different macroinvertebrate metrics (Table 3-6). MCI-sb scores decreased with higher maximum temperatures, lower oxygen minima and lower habitat scores. The proportion of EPT taxa of the macroinvertebrate community was most strongly correlated with temperature maxima, DO minima and habitat score. The proportion of EPT taxa fell as temperatures rose, and as oxygen decreased. MCI-sb scores and proportion of EPT taxa appear to have a threshold temperature of about 21^{o}C, when a marked step change to lower values occurred.

Table 3-6: Correlation of macroinvertebrate metrics with 2-hour maximum stream temperature and 2-hour minimum dissolved oxygen and habitat scores.

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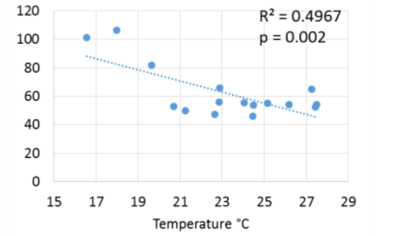
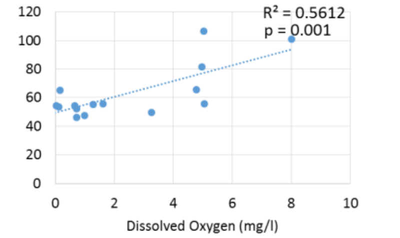
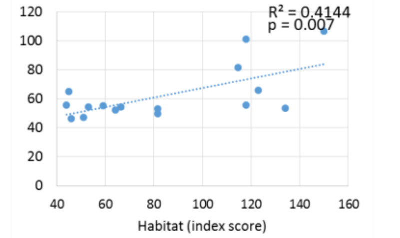
<tr><td>MCI soft bottom</td>
<td></td>
<td></td>
<td></td></tr>
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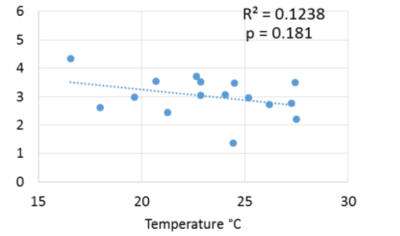
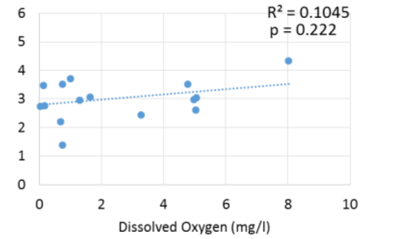
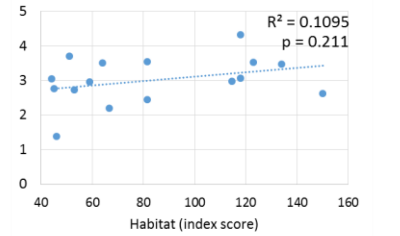
<td></td>
<td></td>
<td></td></tr>
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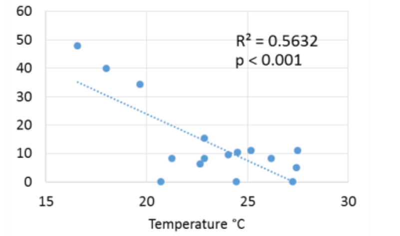
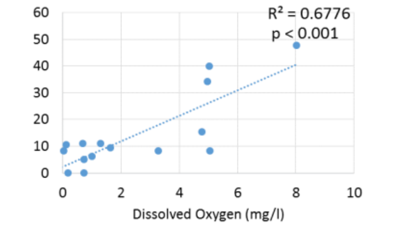
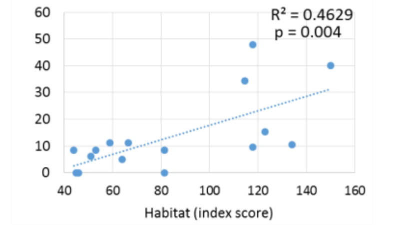
<td></td>
<td></td>
<td></td></tr>
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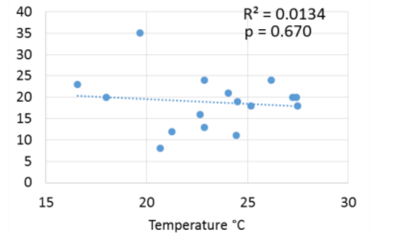
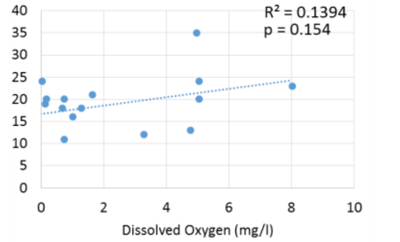
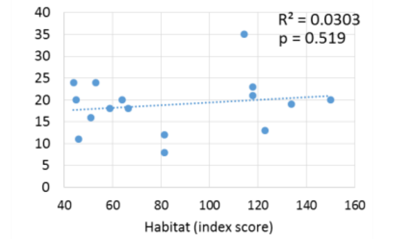
<td></td>
<td></td>
<td></td></tr>
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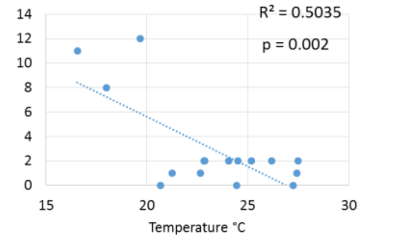
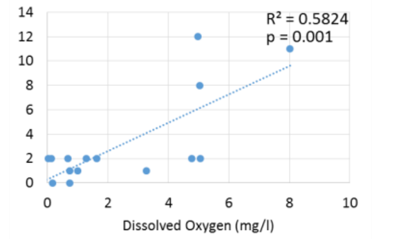
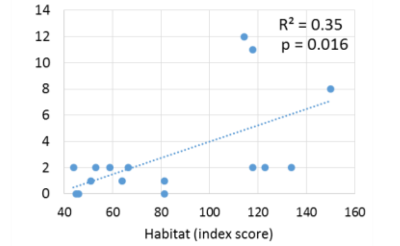
<td></td>
<td></td>
<td></td></tr>
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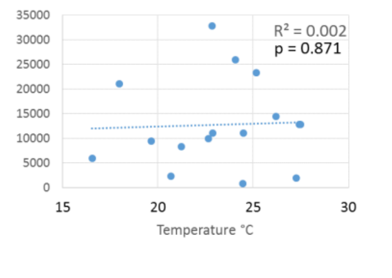
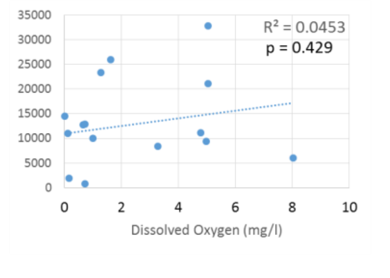
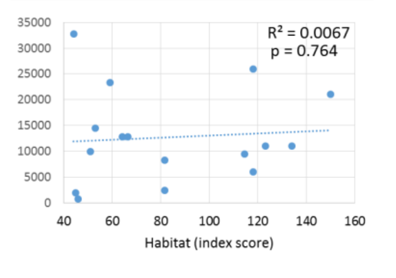
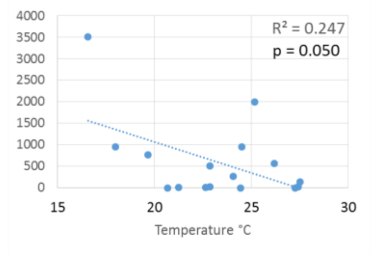
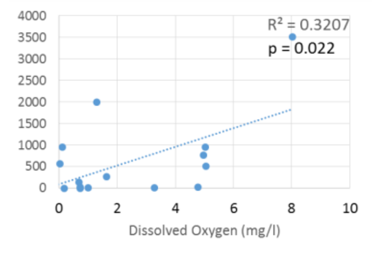
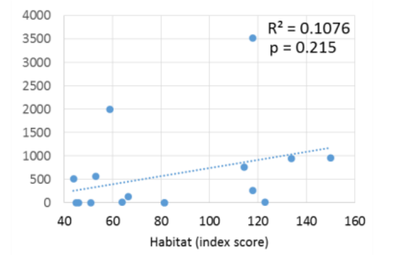
	Metric correlation with temperature	Metric correlation with dissolved oxygen	Metric correlation with habitat score
Total abundance			
EPT abundance			

The QMCI-sb was not significantly correlated with temperature, oxygen or habitat. Likewise taxa richness and macroinvertebrate abundance were not related to either of the three environmental factors, but EPT taxa richness and EPT abundance were correlated with temperature maxima and oxygen minima.

Dissolved oxygen minima correlated slightly better with the tested macroinvertebrate indices than temperature maxima did. This is plausible because the MCI was developed to indicate organic pollution and associated reduction in stream oxygen concentrations. Nevertheless it would be very difficult to separate the respective influences of temperature and oxygen on the macroinvertebrate community, since both factors are highly correlated, one factor being the lower solubility of oxygen in warmer water. Additionally, aquatic organisms need more oxygen in warmer temperatures because their rate of metabolism is elevated.

4 Discussion

This study dealt with the significantly modified lowland streams across the Heretaunga Plains and adjacent catchments. A wide range of environmental variables and potential stressors were measured and tested for correlation with invertebrate community distributions. Sites were chosen to represent a range of environmental conditions and varying macroinvertebrate communities with good to very poor MCI scores. Factors correlated most strongly with changes in the macroinvertebrate community were oxygen minima, temperature maxima, habitat, and oxygen amplitudes (i.e. daily oxygen fluctuation), mean temperature and DRP and TP concentrations.

DRP concentrations are unlikely to have a direct effect on macroinvertebrates, because phosphate at the concentrations measured in this study are not toxic to aquatic organisms (CCME 2004). DRP and TP are present at higher concentrations at sites with high oxygen amplitudes (daily fluctuation) and low oxygen minima. Both these conditions are more likely than DRP or TP to have a direct effect on macroinvertebrates.

The study revealed the importance of water temperature, dissolved oxygen and habitat for the life supporting capacity of the studied streams. Particularly high water temperature and very low DO resulted in a stressed macroinvertebrate community with few examples of the most tolerant species surviving. Life supporting capacity across the Heretaunga Plains and adjacent catchments is heavily affected by high water temperatures and low DO.

4.1 Water temperature

Water temperature is known to have a major influence on aquatic life directly and indirectly, and can chronically affect growth, reproduction and feeding behaviour. More extreme temperatures can lead to acute effects and death of the organism (Olsen, Tremblay et al. 2011).

Critical thermal maxima of 12 New Zealand native fish and 12 native macroinvertebrate species were tested in controlled laboratory experiments by (Olsen, Tremblay et al. 2011). Six out of the 12 macroinvertebrate species were molluscs, worms, shrimps and Hydra *sp*., which all have high thermal tolerances. Three sensitive taxa (Deleatidium *sp*., *Zephlebia dentata* and *Pycnocentria evecta*) had acute thermal criteria[6] between 21°C and 23 °C, calculated as 2 hour average maxima over a 24 hour period. Upper incipient lethal temperature[7] limits for these taxa were between 22°C and 25°C (Quinn, Steele et al. 1994).

Small changes in temperatures of between 2°C and 5°C can be important during all stages in the life cycle of stream invertebrates (Sweeney 1993). Changes in summer mean temperatures (Clapcott, Collier et al. (2012), Lessard and Hayes (2003)) and maximum temperatures (Lowe and Hauer (1999), Sponseller, Benfield et al. (2001)) can significantly influence both macroinvertebrate species composition and abundance. Macroinvertebrate communities in steams from catchments less than 26 km^2 in area were more susceptible to temperature changes than those in rivers with catchment areas greater than 150 km^2 in area in a study by Haidekker and Hering (2007). In these small steams, changes in community composition occurred when mean summer temperature differences were less than 3°C. In the lowland steams of the Karamu and adjacent catchments, which are comparable in area to the small sized streams, the difference in mean temperature between the coolest and warmest streams was 7°C. The associated abundances of community species changed. Several taxa were absent at the warmer sites. Maximum temperature at 8 of the 16 sites exceeded 24°C, with a mean temperature of 20°C. Except for tolerant Hydroptilidae, no EPT taxa were found at these 8 sites. Daily temperature ranges (between 2 and 8°C at the study sites) were found to be insignificant for the macroinvertebrate community. This is consistent with the observation in the study of Haidekker and Hering (2007), in which streams from catchments less than 26 km^2 in area had daily temperature ranges from 4°C to 7.7°C, but no significant effect on the macroinvertebrate community was found.

Te Waikaha, Waitio and Tutaekuri-Waimate water temperatures always remained below 20°C. These sites also had the highest MCI scores and the most diverse EPT community of the study streams. Radon sampling indicated that the Waitio and Tutaekuri-Waimate streams were groundwater influenced at the sampling sites (Appendix B). The groundwater inflows are likely to be the main cause of the cool water temperatures observed, with maximum temperatures of 18°C and 19.7°C respectively. This groundwater inflow is

[6] Acute thermal criteria delineate the point at which thermal stress occurs after short-term exposure and substantial mortality is likely to be observed if those temperatures persist. It is expressed as the daily maximum temperature (DM) defined as the highest two-hour average water temperature measured within any given 24-hour period (Todd, Coleman et al. 2008).

[7] The upper (and lower) incipient lethal temperature is usually defined as the temperature at which 50% mortality occurs in experiments conducted over a set period of time (Olsen, Tremblay et al. 2011).

particularly significant for stream temperature, since neither of these streams have significant riparian vegetation to provide shade to the stream channel.

By contrast, Te Waikaha Stream is not influenced by groundwater at the sampling site. However, water temperature at the site was a maximum of 16.6°C, probably because riparian vegetation fully shades the channel upstream of the sampling site (see upstream riparian vegetation in the site picture for Te Waikaha in Figure 2-3).

4.2 Dissolved oxygen concentration

Dissolved oxygen concentrations were the second critical factor for macroinvertebrate communities in this study. As with temperature, species differ strongly in their oxygen demand, and have species specific oxygen optima and critical thresholds. High water temperatures increase the metabolism of organisms, which increases their oxygen demand (Davis 1975). This effect exacerbates the problem of low dissolved oxygen concentration at the study sites.

Little data is available on dissolved oxygen tolerances of New Zealand species, but it has been assumed that water with a 7 day mean minimum greater than 8 mg/l DO will support the full range of aquatic organisms. Dissolved oxygen concentrations below this level may decrease the abundance and diversity of sensitive species (Davies-Colley, Franklin et al. 2013). In this study, only Te Waikaha Stream stayed above 8 mg/l dissolved oxygen. Ten study sites had oxygen minima of less than 2 mg/l, which are levels that will limit the survival of sensitive aquatic species.

Three main processes are likely to cause low dissolved oxygen conditions:

1) Aquatic plant (including algae) respiration during night-time
2) Oxygen consumption by microbes that break down organic matter
3) Low reaeration of oxygen from the atmosphere which is often found in low gradient streams with reduced flow and/or without flow turbulence typically provided by logs, roots, plants or variable stream banks in lowland streams

Low oxygen concentrations in rivers during the night and early morning hours are caused by excess aquatic plant respiration. Since there is no light for photosynthesis at night, plants respire by using oxygen from the water for their metabolism. Both plant and microbial respiration together can consume more oxygen at night than is produced in the river water, which can result in extreme dissolved oxygen minima, as were observed in this study.

Ecosystem metabolism measurements at the study sites have shown that oxygen uptake through respiration was higher than oxygen production, suggesting that organic matter from the surrounding catchment maintains the ecosystem food chain. This suggests that the respiration rates of above 10 gO_2/m^2/day observed at 11 sites in this study fall into the category of severely impaired ecosystem health (Young, Matthaei et al. 2008).

Reaeration of oxygen from the atmosphere in three streams in the Karamu catchment was studied by (Wilding 2015) in the Awanui, Raupare and Irongate. That work indicated that reduced flow is a contributing factor to critically low dissolved oxygen concentrations.

4.3 Habitat quality

Habitat quality is the third factor highly correlated with macroinvertebrate community composition. Better habitat scores were associated with more sensitive taxa. At the study sites with the poorest macroinvertebrate communities, life supporting capacity is likely to be limited by high water temperature and low dissolved oxygen concentrations in summer, but suitable habitat is another critical factor in these streams. Habitat suitable for a healthy macroinvertebrate community to live and feed on is not found in lowland streams like many of those in the present study, where the streams have straight, uniform channels and soft sediment beds. Suitable stable substrate is important for a successful improvement of the aquatic community. In lowland streams habitat that encourages a more diverse aquatic community is provided by wood, twigs, roots, leaf packs, which also provide cover and habitat for fish (Quinn, Croker et al. (2009); Quinn (2000); Davies-Colley, Meleason et al. (2009); Sweeney and Newbold (2014)).

5 Conclusions and recommendations

Maximum water temperatures and minimum dissolved oxygen concentrations have the most significant effect on macroinvertebrate community compositions. For example, MCI scores were lowest - and sensitive mayflies and caddisflies were absent - at sites with high maximum temperature and low daily oxygen minima.

Given these results, providing shade over the water would be the most effective way to increase the life-supporting capacity of these streams. This is because macrophytes grow less prolifically under shade, resulting in fewer oxygen minima events, which occur when aquatic plants respire and use up oxygen at night. Shade also cools down streams by reducing direct heating from the sun and by creating a microclimate with lower air temperature above the stream channel. As a double benefit cool water also carries more oxygen than warm water. Riparian (river-side) vegetation also improves bank stability, reduces sediment and nutrient inputs, and improves invertebrate and fish habitat.

5.1 Reducing high stream temperatures:

The main influence on water temperature in streams is radiation from the sun. Heat exchange between air and water is less significant, but this effect depends strongly on the water volume, channel shape and flow (Johnson 2004). Open gravel streambeds can reduce temperature maxima, since a significant amount of the water passes through gravel in the hyporheic zone. Water temperatures are lower along this flowpath because the water isn’t in the sun and the water can exchange heat with cooler water deeper in the bed and in contact with groundwater (Johnson 2004). Some cooling may occur by groundwater influx in the soft sediment streams of this study, but since there is no substantial hyporheic zone, temperature buffering does not occur, and direct sunlight is the most important influence on water temperature. Stream channel shade can reduce water temperatures by several degrees Celsius, depending on how complete the shade is, and on the stream size. Small streams benefit the most from shading (Quinn and Wright-Stow (2008); Davies-Colley and Quinn (1998); Meleason and Quinn (2004)). Small narrow streams are more easily shaded than larger streams and riparian plants can provide shade in a short period of time (Rutherford, Davies-Colley et al. 1999).

5.2 Reducing periods of low dissolved oxygen:

Controlling nuisance macrophyte growth is a key tool to mitigate low oxygen conditions in these streams, since these plants consume oxygen by respiration at night. Figure 5-1 shows an overview of factors that control macrophyte growth, together with those that control algal/periphyton growth: the wider the arrows in the diagram the stronger the relative degree of influence on macrophyte and algal growth.

Rooted macrophytes can take up nutrients both in dissolved form from the water column through their leaves, and also from the sediment through the root system. Since they are able to obtain nutrients from the sediment, their growth is restricted only by very low concentrations of dissolved nutrients. As a consequence it is unlikely to be feasible to control macrophytes by reducing dissolved nutrient concentrations in the nutrient rich lowland streams of the Karamu catchment.

Substrate type is another important factor for macrophyte growth, with species capable of forming nuisance growth being most abundant on silt, sand and small gravel beds (Riis and Biggs 2003). This is the dominant substrate type in the typically low-gradient Karamu catchment.

Macrophyte growth can be controlled most effectively by reducing the light levels (Figure 5-1). Riparian vegetation reduces the amount of light available for the growth of macrophytes by providing shade.

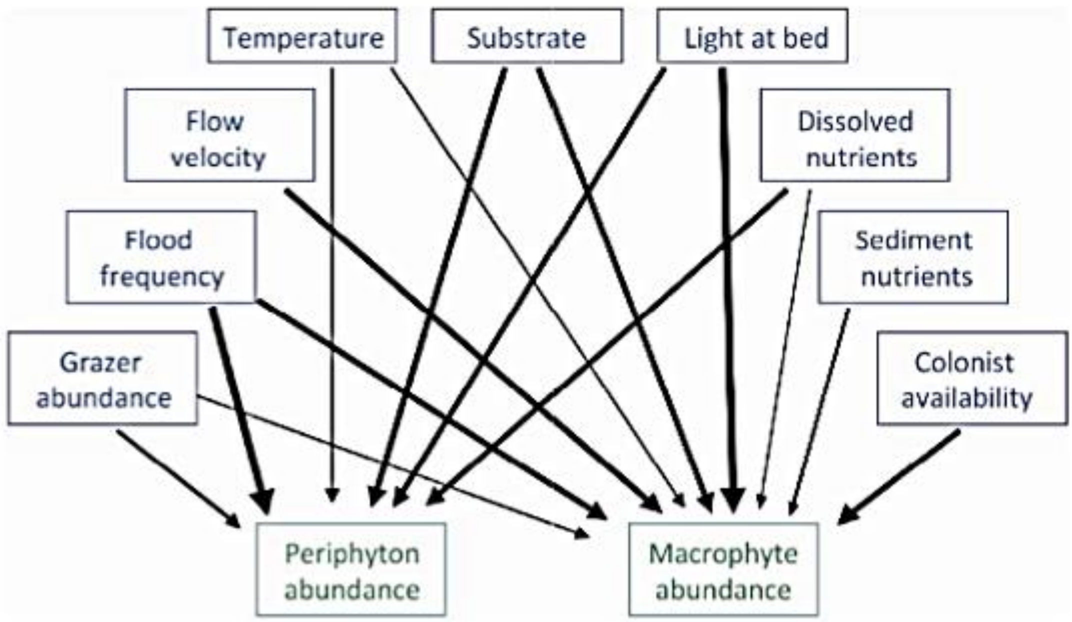


Figure 5-1: Key variables regulating instream nuisance plant abundance (from Matheson *et al.* 2012). Wider arrows indicate a stronger relative degree of influence.

5.3 Improvement of habitat

Another stressor on the aquatic community identified in this study was poor habitat in the straightened, uniform, soft sediment channels. Logs, twigs, roots and leaf litter provide hydraulic complexity, cover, habitat and a food source for aquatic organisms. If targeted and effective riparian management using the correct riparian plants was used to reduce temperature extremes and limit macrophyte growth, then habitat would also benefit (Meleason and Hall (2005); Quinn, Croker et al. (2009)).

6 Acknowledgements

Special thanks to Annika Wagenhoff (Cawthron Institute) for reviewing the report and the helpful recommendations, and to Roger Young (Cawthron Institute) and Russell Death (Massey University) for the valuable comments regarding the study design, the statistical approach and the report. I am grateful for the many helpful discussions with Adam Uytendaal. The input from Dougall Gordon, Keiko Hashiba, Andy Hicks, Barry Lynch, Stephen Swabey, Rob Waldron, and Thomas Wilding was much appreciated. Thank you also to McKay Dawson for leading the fieldwork in this project, and to Heli Wade for providing the maps for the report.

7 References

ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Canberra, Australian and New Zealand Environment and Conservation Council. Agriculture and Resource Management Council of Australia and New Zealand.

Biggs, B. (2000). New Zealand Periphyton Guidelines: Detecting, Monitoring and Managing Enrichment of Streams Prepared for the Ministry for the Environment, National Institute for Water and Atmospheric Research (NIWA).

Cameron, D. (2010). Stream Ecological Valuation: Upper Karamu Waterways., MWH New Zealand Limited.

CCME (2004). Phosphorus: Canadian Guidance Framework for the Management of the Freshwater Systems. C. C. o. M. o. t. Environment.

Clapcott, J., R. Young, E. Goodwin, J. Leathwick and D. Kelly (2011). Relationships between multiple land-use pressures and individual and combined indicators of stream ecological integrity. DOC Research and Development Series 326, New Zealand Department of Conservation.

Clapcott, J. E. (2013). Rapid Habitat Assessment Workshop., Cawthron Institute.

Clapcott, J. E., K. J. Collier, R. G. Death, E. O. Goodwin, J. S. Harding, D. Kelly, J. R. Leathwick and R. G. Young (2012). "Quantifying relationships between land-use gradients and structural and functional indicators of stream ecological integrity." Freshwater Biology **57**: 74–90.

Davies-Colley, R. J., P. Franklin, B. Wilcock, S. Clearwater and C. Hickey (2013). National Objectives Framework - Temperature, Dissolved Oxygen & pH. Proposed thresholds for discussion. NIWA Client Report: HAM2013-056. NIWA Project: MFE13504, NIWA. **Prepared for Ministry for the Environment:** 83 pp.

Davies-Colley, R. J., M. A. Meleason, R. M. J. Hall and J. C. Rutherford (2009). "Modelling the time course of shade, temperature, and wood recovery in streams with riparian forest restoration." New Zealand Journal of Marine and Freshwater Research **43:3**: 673-688.

Davies-Colley, R. J. and J. M. Quinn (1998). "Stream lighting in five regions of North Island, New Zealand: Control by channel size and riparian vegetation." New Zealand Journal of Marine and Freshwater Research **32**(4).

Davis, C. D. (1975). "Minimal Dissolved Oxygen Requirements of Aquatic Life with Emphasis on Canadian Species: a Review." Journal of the Fisheries Research Board of Canada **32**(12): 2295-2332.

European_Chemicals_Bureau (2008). "Diphenylamine Summary Risk Assessment Report." European Chemicals Bureau – Existing Chemicals – http://ecb.jrc.it **CAS No 122-39-4**(EINECS No: 204-539-4).

European_Commission (2006) "Institute for Health and Consumer Protection European Chemicals Bureau I-21020 Ispra (VA) Italy 2006. 3,4-dichloroaniline (3,4-DCA) Summary Risk Assessment Report." Institute for Health and Consumer Protection European Chemicals Bureau I-21020 Ispra (VA) Italy.

Forbes, A. (2011). Stream Ecological Valuation: Ruahapia and Raupare Streams., MWH New Zealand Limited.

Forbes, A. and D. Cattin (2009). Stream Ecological Valuation: Napier Urban Streams. , MWH New Zealand Limited.

Haidekker, A. and D. Hering (2007). "Relationship between benthic insects (Ephemeroptera, Plecoptera, Coleoptera, Trichoptera) and temperature in small and medium-sized streams in Germany: A multivariate study. ." Aquat. Ecol. **42**: 463–481.

HBRC (2014). Karamu Characterisation Report - Supporting Information for Water Allocation. . HBRC Report No. EMT13/24 – 4557., Hawke's Bay Regional Council, Napier.

Johnson, S. L. (2004). "Factors influencing stream temperatures in small streams: substrate effects and a shading experiment." Canadian Journal of Fisheries and Aquatic Sciences **61**: 913-923.

Leathwick, J., K. Julian, J. Elith, L. Chadderton, S. Ferrier and T. Snelder (2010). "A biologically-optimised environmental classification of New Zealand rivers and streams: reanalysis excluding human impacts variables." Biological Conservation **143**(4): 984-991.

Lessard, J. L. and D. B. Hayes (2003). "Effects of elevated water temperature on fish and macroinvertebrate communities below small dams." River Res. Applic. **19**: 721–732.

Lowe, W. H. and F. R. Hauer (1999). "Ecology of two large, net-spinning caddisfly species in a mountain stream: distribution, abundance, and metabolic response to a thermal gradient." Can J Zool **77**: 1673–1644.

Matheson, F., J. Quinn and C. Hickey (2012). Review of the New Zealand in-stream plant and nutrient guidelines and development of an extended decision making framework. Phases 1 and 2 final report. Prepared for the Ministry of Science and Innovation Envirolink fund, NIWA**:** 127pp.

Meleason, M. A. and G. M. Hall (2005). "Managing plantation forests to provide short-to long-term supplies of wood to streams: a simulation study using New Zealand's pine plantations." Environmental Management **36**(2): 258-271.

Meleason, M. A. and J. M. Quinn (2004). "Influence of riparian buffer width on air temperature at Whangapoua Forest, Coromandel Peninsula, New Zealand." Forest ecology and management **191**(1): 365-371.

MfE (2014). National Policy Statement for Freshwater Management 2014. Wellington, Ministry for the Environment.

NPIC (2000). "DDT Technical Fact Sheet." National Pesticide Information Center.

Olsen, D. A., L. Tremblay, J. Clapcott and R. Homes (2011). Water Temperature Criteria for Native Aquatic Biota. . Prepared for Auckland Council, Environment Waikato and Hawkes Bay Regional Council, Cawthron Institute. **Cawthron Report No. 2024:** 80 pages plus appendices.

Owens, M. (1974). Measurements on non-isolated natural communities in running waters. A manual on methods for measuring primary production in aquatic environments. Blackwell Scientific Publications, Oxford, UK, 111-119. Oxford, UK, Blackwell Scientific Publications**:** 111-119.

Quinn, J., L. Steele, C. W. Hickey and M. Vickers (1994). "Upper thermal tolerances of twelve New Zealand stream invertebrate species." New Zealand Journal of Marine and Freshwater Research **28**: 391-397.

Quinn, J. M. (2000). Effects of pastoral development. New Zealand stream invertebrates: ecology and implications for management. K. J. Collier and M. J. Winterbourn. Christchurch, Caxton Press**:** 208-229.

Quinn, J. M., G. F. Croker, B. J. Smith and M. A. Bellingham (2009). "Integrated catchment management effects on flow, habitat, instream vegetation and macroinvertebrates in Waikato, New Zealand, hill-country streams." New Zealand Journal of Marine and Freshwater Research **43:3**: 775-802.

Quinn, J. M. and A. E. Wright-Stow (2008). "Stream size influences stream temperature impacts and recovery rates after clearfell logging." Forest Ecology and Management. **256**(12): 2101-2109.

Riis, T. and B. J. F. Biggs (2003). "Hydrologic and hydraulic control of macrophyte establishment and performance in streams." American Society of Limnology and Oceanography **48**(4): 1488–1497.

Rowe, D., J. Quinn, S. Parkyn, K. Collier, C. Hatton, M. Joy, J. Maxted and S. Moore (2006). Stream Ecological Valuation (SEV): a method for scoring the ecological performance of Auckland streams and for quantifying mitigation., Auckland Regional Council.

Rutherford, J. C., R. Davies-Colley, J., J. M. Quinn, M. J. Stroud and A. B. Cooper (1999). Stream shade: towards a restoration strategy. , Department of Conservation, Wellington, NZ**:** 159 p.

Snelder, T., B. J. Biggs and M. Weatherhead (2010). New Zealand River Environment Classification User Guide. Publication number: ME 1026 ISBN: 978-0-478-33295-7, Ministry for the Environment.

Sponseller, R. A., E. F. Benfield and H. M. Valett (2001). "Relationships between land use, spatial scale and stream macroinvertebrate communities." Freshwater Biology **46**: 1409–1424.

Stansfield, B. (2009). Urban streams of the Napier Catchment. Water Quality and Ecology 2008/09., Hawke's Bay Regional Council. .

Stark, J. D. (1985). A macroinvertebrate community index of water quality for stony streams, Ministry of Works and Development. **Water & Soil Miscellaneous Publication, N.87**.

Stark, J. D., I. K. G. Boothroyd, J. R. Harding and M. R. Scarsbrook (2001). Protocols for sampling macroinvertebrates in wadeable streams. Report No.1. N. Z. M. W. Group, Prepared for Ministry for the Environment.

Stark, J. D. and J. R. Maxted (2007). A user guide for the Macroinvertebrate Community Index**:** 58 pp.

Sweeney, B. W. (1993). "Effects of Streamside Vegetation on Macroinvertebrate Communities of White Clay Creek in Eastern North America." Proceedings of The Academy of Natural Sciences of Philadelphia(144): 291–340.

Sweeney, B. W. and J. D. Newbold (2014). "Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review." Journal of the American Water Resources Association (JAWRA)(50(3)): 560-584.

Todd, A. S., M. A. Coleman, A. M. Konowal, M. K. May, S. Johnson, N. K. Vieira and J. F. Saunders (2008). "Development of new water temperature criteria to protect Colorado's fisheries." Fisheries **33**(9): 433-443.

Wilcock, B., R. Young, M. Gibbs and G. McBride (2011). Continuous measurement & interpretation of dissolved oxygen data in rivers. NIWA Client Report No: HAM2011-010. P. f. H. R. Council, NIWA, Hamilton, NZ.

Wilding, T. (2015). Karamu Catchment. Instream Flows for Oxygen., Hawke's Bay Regional Council.

Young, R. G. and B. R. Knight (2005). River Metabolism Estimator. Developed for Ministry for the Environment. **SMF Project 2208**.

Young, R. G., C. D. Matthaei and C. R. Townsend (2008). "Organic matter breakdown and ecosystem metabolism: functional indicators for assessing river ecosystem health." Journal of the North American Benthological Society **27**: 605-625.

Young, R. G., C. R. Townsend and C. D. Matthaei (2004). Functional indicators of river ecosystem health – an interim guide for use in New Zealand. P. f. t. M. o. t. Environment.

Young, R. G., C. R. Townsend and C. D. Matthaei (2006). Functional indicators of river ecosystem health - final project report. N. Prepared for Ministry for the Environment.

Appendix A Outline for deployment of DO and temperature loggers and sampling

Two permanently installed loggers in the Raupare and Awanui streams recorded dissolved oxygen (DO) and temperature (Temp) over the study period. Start logging: date of deployment of DO/temperature loggers. Water quality and ecology sample dates in the respective Period 1 to Period 6 columns.

Period	P1	P2	P3	P4	P5	P6
START logging DO/Temp	11/02/14	14/02/14	18/02/14	21/02/14	25/02/14	28/02/14
Raupare	13/02/14					
Awanui Pakipaki		17/02/14				
Herehere	13/02/14					
Taipo						
Karewarewa Pakipaki		17/02/14				
Poukawa						
Tutaekuri-Waimate			20/02/14			
Irongate						
Waitio						
Papanui Middle Rd				24/02/14		
Papanui U/S Kaikora						
Karewarewa Turamoe Rd						
Te Waikaha					27/02/14	
Louisa Strm						
Ruahapia						
Awanui at Turamoe Rd						04/03/14

Appendix B Average air and water temperature over the recording period

Average air and water temperature over the recording period and site deployment periods from the 11th February to 4th March 2014. Air temperature obtained from the Bridge Pa climate station and water temperature recorded over the monitoring time period at the Awanui at Pakipaki and Raupare at Ormond Road sites with permanently installed loggers.

	Bridge Pa air temp. (°C)	Raupare water temp. (°C)	Awanui water temp. (°C)	Bridge Pa air temp. (°C)	Raupare water temp. (°C)	Awanui water temp. (°C)
average total period (11/02/14 – 04/03/14)	18.4	17.5	20.5	deviation from average		
average P1 (11/02– 14/02)	18.8	17.7	20.2	0.3	0.1	-0.3
average P2 (14/02 – 18/02)	18.7	17.6	20.6	0.3	0.0	0.1
average P3 (18/02 – 21/02)	20.5	18.0	22.3	2.0	0.5	1.8
average P4 (21/02 – 25/02)	22.1	18.3	23.2	3.6	0.8	2.7
average P5 (25/02 – 28/02)	16.4	16.7	18.6	-2.0	-0.8	-2.0
average P6 (28/02 – 04/03)	15.7	17.0	18.4	-2.8	-0.6	-2.1

Appendix C Pesticides in streambed sediment tested

Multiresidue Pesticides [mg/kg dry wt]			
Acetochlor	2,4'-DDD	Haloxyfop-methyl	Prochloraz
Alachlor	4,4'-DDD	Heptachlor	Procymidone
Aldrin	2,4'-DDE	Heptachlor epoxide	Prometryn
Atrazine	4,4'-DDE	Hexachlorobenzene	Propachlor
Atrazine-desethyl	2,4'-DDT	Hexaconazole	Propanil
Atrazine-desisopropyl	4,4'-DDT	Hexazinone	Propazine
Azaconazole	Total DDT Isomers	Hexythiazox	Propetamphos
Azinphos-methyl	Deltamethrin (including Tralomethrin)	Imazalil	Propham
Benalaxyl	Diazinon	Indoxacarb	Propiconazole
Bendiocarb	Dichlobenil	Iodofenphos	Prothiofos
Benodanil	Dichlofenthion	IPBC (3-Iodo-2-propynyl-n-butylcarbamate)	Pyrazophos
alpha-BHC	Dichlofluanid	Isazophos	Pyrifenox
beta-BHC	Dichloran	Isofenphos	Pyrimethanil
delta-BHC	Dichlorvos	Kresoxim-methyl	Pyriproxyfen
gamma-BHC (Lindane)	Dicofol	Leptophos	Quintozene
Bifenthrin	Dicrotophos	Linuron	Quizalofop-ethyl
Bitertanol	Dieldrin	Malathion	Simazine
Bromacil	Difenoconazole	Metalaxyl	Simetryn
Bromophos-ethyl	Dimethoate	Methacrifos	Sulfentrazone
Bromopropylate	Dinocap	Methamidophos	Sulfotep
Bupirimate	Diphenylamine	Methidathion	TCMTB [2-(thiocyanomethylthio)
Buprofezin	Diuron	Methiocarb	Tebuconazole
Butachlor	Endosulfan I	Methoxychlor	Tebufenpyrad
Captafol	Endosulfan II	Metolachlor	Terbacil
Captan	Endosulfan sulphate	Metribuzin	Terbumeton
Carbaryl	Endrin	Mevinphos	Terbuthylazine
Carbofenothion	Endrin aldehyde	Molinate	Terbuthylazine-desethyl
Carbofuran	Endrin ketone	Myclobutanil	Terbutryn
cis-Chlordane	EPN	Naled	Tetrachlorvinphos
trans-Chlordane	Esfenvalerate	Nitrofen	Thiabendazole
Total Chlordane [(cis+trans)*	Ethion	Nitrothal-isopropyl	Thiobencarb
Chlorfenvinphos	Etrimfos	Norflurazon	Tolylfluanid
Chlorfluazuron	Famphur	Omethoate	Triadimefon
Chlorothalonil	Fenamiphos	Oxadiazon	Triazophos
Chlorpropham	Fenarimol	Oxychlordane	Trifluralin wt
Chlorpyrifos	Fenitrothion	Oxyfluorfen	Vinclozolin
Chlorpyrifos-methyl	Fenpropathrin	Paclobutrazol	
Chlortoluron	Fenpropimorph	Parathion-ethyl	
Chlozolinate	Fensulfothion	Parathion-methyl	
Coumaphos	Fenvalerate	Penconazole	
Cyanazine	Fluazifop-butyl	Pendimethalin	
Cyfluthrin	Fluometuron	Permethrin	
Cyhalothrin	Flusilazole	Phosmet	
Cypermethrin	Fluvalinate	Phosphamidon	
Cyproconazole	Folpet	Pirimicarb	
Cyprodinil	Furalaxyl	Pirimiphos-methyl	

The laboratory's default detection limit for multiresidue pesticides in sediment was 0.003 – 0.06 mg/kg dry weight. The tested pesticides as listed above were below detection limit across all study sites except for:

Taipo Stream:	Diuron	0.009 mg/kg dry weight
Ruahapia Stream:	4,4'-DDD	0.015 mg/kg dry weight
	4,4'-DDE	0.011 mg/kg dry weight
	4,4'-DDT	0.028 mg/kg dry weight
	Diphenylamine	0.08 mg/kg dry weight

Appendix D Groundwater influence measured at selected sites as Radon (Bq/L)

Stream	Site Location	Radon (Bq/L)[1]	Groundwater Influence
Raupare	at Ormond Road	4	YES
Karewarewa	at Pakipaki	0.7	Unlikely
Awanui	at Pakipaki	0.9	Unlikely
Poukawa	at Stock Road	0.3	NIL
Te Waikaha	at Mutiny Road	0.1	NIL
Waitio	at Ohiti Road	7.5	YES
Tutaekuri - Waimate	upstream Ngaruroro	2.9	YES

[1]Above 0.5 Bq/L indicates some groundwater influx; 30-40 Bq/L is likely to be pure groundwater.

Appendix E Macroinvertebrate Taxa List

		Papanui Strm at Middle Rd	Papanui Strm US Kaikora Drain	Herehere Strm at Te Aute Rd	Herehere Strm at Te Aute Rd	Raupare Strm at Ormond Rd	Raupare Strm at Ormond Rd	Raupare Strm at Ormond Rd	Taipo Strm at Church Rd	Tutaekuri-Waimate Strm	Irongate at Riverslea Rd
		(blank)	(blank)	1 (MH)	2 (C2)	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)
		24-02-1	24-02-1	13-02-1	13-02-1	13-02-1	21-01-1	26-11-1	13-02-1	20-02-1	20-02-1
Faunal Grouping	MCI-level name	I140414	I140415	I140417	I140454	I140418	I140431	I140433	I140419	I140420	I140421
Acari	Acari		6.3	12.7		19.0	2.7	5.3			6.35
Coelenterata	Hydra			63.5		6.3		5.3			
Coleoptera	Antiporus			6.3		1.6	10.7	1.3		1.6	
	Elmidae									25.4	
	Enochrus										
	Liodessus										
Crustacea	Amphipoda										
	Cladocera										
	Copepoda	44.4	25.4	63.5	5.3	158.7	8.0	5.3		6.3	6.35
	Ostracoda	315.6	101.6	838.1	21.3	2400	77.3	658.7	3.2	107.9	3308
	Paracalliope	4884	8349	16444	5409	10940	2544	4419		1994	819
	Paranephrops						1.3	1.3		3.2	
	Paratya									4.8	
Diptera	Austrosimulium		196.8								
	Ceratopogonidae		6.3			44.4	2.7	5.3	6.3		
	Chironomidae	142.2				6.3	18.7			12.7	
	Chironomus	17.8	6.3			12.7	10.7	5.3			6.35
	Corynoneura			19.0	10.7	6.3	32.0				
	Ephydridae										
	Hexatomini										
	Mischoderus			3.2							
	Orthocladiinae	8.9	127.0	6.3	5.3	120.6	96.0		14.3	114.3	63.49
	Paradixa										
	Psychodidae										
	Tanypodinae	8.9								3.2	
	Tanytarsini	191.1	25.4				64.0		39.7	31.7	6.35
Hemiptera	Anisops										
	Microvelia			12.7	5.3	38.1					
	Sigara		3.2			31.7	10.7		58.7	19.0	6.35
Hirudinea	Hirudinea	115.6	57.1	12.7					4.8	6.3	
Lepidoptera	Hygraula	35.6	12.7			1.6				1.6	1.59
Mollusca	Ferrissia						10.7			12.7	
	Gyraulus	8.9	196.8	25.4	5.3	101.6	21.3			12.7	222.22
	Lymnaeidae						1.3				
	Physa	124.4	311.1	50.8	21.3	298.4	173.3	69.3	3.2	254.0	431.75
	Potamopyrgus	3049	13879	16895	5520	17448	5723	16192		4711	7162
	Sphaeriidae			69.8		304.8	32.0	744.0		19.0	50.79
Nematoda	Nematoda	80.0	19.0			19.0		10.7		12.7	25.40
Odonata	Hemianax								1.6		
	Ishnura										
	Xanthocnemis	133.3	215.9	38.1		12.7	34.7	8.0	3.2	6.3	
Oligochaeta	Oligochaeta	764.4	1320.6	247.6	5.3	25.4	290.7	1770.7	28.6	1301.6	279.37
Platyhelminthes	Platyhelminthes	124.4	831.7	203.2	52.0	285.7	53.3		641.3	6.3	228.57
Trichoptera	Aoteapsyche									31.7	
	Hudsonema			25.4	10.7			5.3		12.7	
	Hydrobiosis							2.7		1.6	
	Olinga									6.3	
	Orthopsyche										
(Hydroptilidae)	Oxyethira	835.6	184.1	12.7		393.7	181.3	26.7		488.9	25.40
(Hydroptilidae)	Paroxyethira	111.1	76.2	114.3		120.6	40.0			114.3	107.94
	Polyplectropus									6.3	
	Psilochorema						2.7			6.3	
	Pycnocentria									6.3	
	Pycnocentrodes									19.0	
	Triplectides			6.3						57.1	
Ephemeroptera	Austroclima							1.3			
	Coloburiscus										
	Deleatidium									12.7	
	Zephlebia				6.7						

	Waitio Strm at Ohiti Rd	Awanui Strm at Flume	Awanui Strm at Flume	Awanui Strm at Flume	Poukawa Strm at Stock Rd	Karewarewa Strm at Pakipaki	Te Waikaha Strm at Mutiny Rd	Te Waikaha Strm at Mutiny Rd	Louisa Strm at Te Aute Rd	Ruahapia Strm at Show Gr	Awanui Strm at Turamoe Rd	Karewarewa at Turamoe Rd
	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)	1 (MH)	2 (C2)	(blank)	(blank)	(blank)	(blank)
4	20-02-14	17-02-14	21-01-14	26-11-13	17-02-14	17-02-14	27-02-14	27-02-14	27-02-14	27-02-14	04-03-14	24-02-14
MCI-level name	I140422	I140423	I140430	I140432	I140424	I140425	I140426	I140453	I140427	I140428	I140429	I140416
Acari				5.33								
Hydra	8.89		2.67	21.33		8.89						82.54
Antiporus		6.35		5.33				5.33			3.17	
Elmidae	40.00			2.67		88.89	19.05					
Enochrus		12.70			1.59						9.52	
Liodessus											3.17	6.35
Amphipoda							25.40					
Cladocera		825.40	301.33									1136.51
Copepoda		101.59			317.46	53.33	6.35	10.67			50.79	920.63
Ostracoda	53	29	133	43	108	133			10	13	19	286
Paracalliope	267	3473	1989	5037	5492	6702	1930	3291	990		251	7029
Paranephrops							3.17					
Paratya												
Austrosimulium	106.67						95.24	5.33				
Ceratopogonidae		3.17				26.67					9.52	
Chironomidae	115.56		5.33				6.35	10.67		12.70		
Chironomus			2.67							1533.33	47.62	19.05
Corynoneura					6.35							
Ephydridae		6.35	5.33		6.35							
Hexatomini							1.59					
Mischoderus												
Orthocladiinae	391.11	326.98	5.33	8.00	76.19	26.67		10.67	6.35		19.05	12.70
Paradixa								90.67				
Psychodidae					6.35							
Tanypodinae		12.70		2.67			6.35	5.33			3.17	
Tanytarsini	71.11	250.79	8.00						3.17		190.48	120.63
Anisops			1.33	10.67								
Microvelia	4.44	19.05	24.00	106.67			31.75	186.67		79.37	3.17	82.54
Sigara		9.52	16.00	45.33						9.52	349.21	25.40
Hirudinea		19.05	10.67	2.67	1.59	2.22				6.35	101.59	25.40
Hygraula		1.59										
Ferrissia												
Gyraulus		12.70	26.67			160.00					82.54	380.95
Lymnaeidae												
Physa	177.78	79.37	186.67	117.33	1.59	35.56		1.33	298.41	6.35		38.10
Potamopyrgus	1133	7952	8483	4600	3676	13467	17987	5723	6460		60	1194
Sphaeriidae									130.16			
Nematoda		25.40	5.33	16.00	12.70	8.89			3.17		31.75	12.70
Hemianax												
Ishnura						44.44						
Xanthocnemis		431.75	445.33	61.33	12.70	71.11		48.00	50.79		31.75	114.29
Oligochaeta	84.44	117.46	181.33	376.00	63.49	106.67			342.86	711.11	247.62	139.68
Platyhelminthes		187.30	45.33	34.67	171.43	373.33	6.35	5.33	25.40		400.00	1187.30
Aoteapsyche	217.78							1.33				
Hudsonema	4.44							1.33				
Hydrobiosis	8.89											
Olinga	404.44											
Orthopsyche							76.19					
Oxyethira		501.59	13.33	16.00	6.35	1146.67		10.67	6.35			
Paroxyethira		66.67		5.33		844.44						19.05
Polyplectropus	2.22							21.33				
Psilochorema	40.00						1.59					
Pycnocentria	426.67						63.49	90.67				
Pycnocentrodes	1600.00						6.35					
Triplectides							12.70	21.33				
Austroclima	195.56						476.19	16.00				
Coloburiscus							95.24	5.33				
Deleatidium	520.00											
Zephlebia	97.78						222.22	149.33				

Appendix F Habitat Assessment Protocol

1. Fine sediment deposition in naturally hard-bottomed streams	<10% of the streambed in run habitats covered by fine sediment	10-20% of the streambed in run habitats covered by fine sediment	20-50% of the streambed in run habitats covered by fine sediment; score lower if deposits are deep	>50% of the streambed in run habitats covered by fine sediment; score lower if deposits are deep
Example score	*20 = 0%, 16 = 8%*	*15 = 10%, 11 = 18%*	*Thin film: 10 = 30%, 9 = 35%, 8 = 40%, 7 = 45%, 6 = 50%*	*Thin film: 5 = 60%, 4 = 70%, 3 = 80%, 2 = 90%, 1 = 100%*
			Deep/sandy deposits: 10 = 20%, 9 = 25%, 8 = 30%, 7 = 35%, 6 = 40%	*Deep/sandy deposits: 5 = 55%, 4 = 60%, 3 = 65%, 2 = 70%, 1 = 75%+*
SCORE ___	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
2. Invertebrate habitat	Abundant and diverse	Common and adequate	Patchy and limited	Rare or absent
	>75% substrate favourable for EPT colonisation. Present year-round.	50-75% substrate favourable for EPT. Some habitat may be transient or not persist beyond a season.	25-50% substrate favourable for EPT. Score lower if large proportion of habitat not persistent.	<25% substrate favourable for EPT.
	<u>*and*</u>	<u>*and*</u>	<u>*and*</u>	<u>*and*</u>
	Wide variety (> 5 types) of substrate sizes and types. Inorganic includes boulders, cobbles, gravels, sand. Organic includes wood, leaves, root mats, macrophytes.	Moderate variety (4-5 types) of substrate sizes and types.	Limited variety (2-3 types) of substrate sizes and types.	Homogenous substrate (predominantly 1 substrate type).
	<u>*and*</u>	<u>*and*</u>	<u>*and*</u>	<u>*and*</u>
	Interstitial spaces open.	Interstitial spaces open.	Interstitial spaces limited.	Very limited interstitial space.
Example score	*20 = 95% cobbles & gravels, with boulders, sand, wood & leaves present.*	*15 = 70% stable substrate with 4 additional substrate types*	*10 = 50% cobble/gravel with leaves and small wood with 25% periphyton/macrophyte cover*	*5 = 25% gravel rest of stream covered in unstable sands*

	19 = 90%, 18 = 85%, 17 = 80%, 16 = 75%	*11 = 50% stable substrate and macrophytes/periphyton present*	*6 = 30% cobble/gravel with leaves and small wood, with >40% periphyton/macrophyte growth*	*1 = 5% gravel rest of stream covered in silt/mud*
SCORE ___ x 2	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
3. Fish cover	Abundant and diverse	Common and adequate	Patchy and limited	Rare or absent
	>70% fish cover in reach	40-70% fish cover	10-40% fish cover	<10% fish cover
	and	*and*	*and*	*and*
	Wide variety (≥4) of persistent fish cover providing spatial complexity such as woody debris, root mats, undercut banks, overhanging/ encroaching vegetation, macrophytes, boulders, cobbles	Moderate variety (3) of fish cover types providing spatial complexity; woody debris and overhanging vegetation or undercut banks score higher if persistent	Limited variety (2) of fish cover types, woody debris, overhanging vegetation or undercut banks are rare; only larger cover elements are persistent	Fish cover rare or absent; few hiding places or interstitial spaces
Example score	*20 = 95% of habitat favoured by expected fish community, lots instream and bank complexity*	*15 = 70% of habitat favoured by expected fish community, o/hanging veg/banks stable*	*10 = 40%, fish cover is boulders and logs in water*	*5 = 8%, fish cover is a few seasonal macrophytes instream*
	19 = 90%, 18 = 85%, 17 =80%, 16 = 75%	*11 = 40%*	*6 = 10%*	*1 = 0% fish cover, uniform substrate*
SCORE ___ x 2	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
4. Hydraulic heterogeneity	Wide variety (4+) of hydraulic components such as pool, riffle, run, glide, chute, waterfalls (appropriate to gradient of the site)	Moderate variety (3) of hydraulic components, scores lower if riffle habitat relatively scarce	Limited variety (2) of hydraulic components (e.g. a run and a riffle)	Uniform depth and velocity
	and	*and*	*and*	*and*
	Variety of pool sizes and depths (appropriate to size of stream)	Deep and shallow pools present (pool size relative to stream size)	Deep pools absent (pool size relative to stream size)	Pools absent (includes uniformly deep streams)

Example score	*20 = riffle run pool and backwaters with shallow and deep pools*	*15 = runs pools riffles*	*10 = run riffle but pools only after riffles*	*5 = mainly run/glide, pools or riffle hard to find*
	16 = riffle run pool, backwaters hard to find	*11 = runs pools but less riffles*	*6 = no deep pools*	*1 = no pools*
SCORE ___	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
5. Bank stability	High	Moderate	Low	Very low
	Banks stabilised by geology, vegetation cover and/or deep roots (1-2x bank height)	Banks stabilised by geology, moderate vegetation cover and/or root depth	Uncohesive bank materials, sparse vegetation cover and/or shallow roots (< bank height)	Uncohesive bank materials and few roots
	and	*and*	*and*	*and*
	<5% recently eroded, mainly scouring	5-30% recently eroded, mainly scouring	30-60% recently eroded, mainly slumping	>60% recently eroded, mainly slumping
Example score	*20 = mature bank vegetation, no sign of erosion*	*15 = 5% erosion scars at water line*	*10 = 30% erosion, slumping of bank above water line*	*5 = 65% erosion scars, slumping of bank above water line*
	16 = younger bank vegetation, limited erosion at water line	*14 = 10%, 13 = 15%, 12 = 20%, 11 = 25%*	*9 = 40%, 8 = 45% , 7 = 55%, 6 = 60%*	*4 = 75%, 3 = 80%, 2 = 85%, 1 ≥ 90%*
Left bank	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
Right bank	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
SCORE (mean LB&RB) ___				
6. Bank vegetation	Mature native vegetation, with diverse and intact understorey and groundcover	Regenerating native vegetation or mature with damaged understorey or dense mature exotic vegetation or dense mature flaxes/sedges	Shrubs or sparse tree cover with little understorey vegetation or long grasses or early-stage planted trees	Heavily grazed or mown grass or bare ground or impervious cover

Example score	*20 = mixed age and height vegetation within 5 m of wetted width, 16 = mixed veg but less mature trees, gaps in groundcover*	*15 = young native veg, 14 = native but understorey damage obvious, 13 = low native veg only, 12 = mix mature exotic trees and native, 11 = mature exotic trees dominate*	*10 = mix native and exotic young veg, 9 = mix with some high trees, 8 = mix mainly shrubs, 7 = mix veg mainly grass, 6 = mainly young exotic*	*5 = mainly exotic grass, 4 = mown grass, 3 = bare ground, 2 = impervious cover, 1 = no bank veg*
Left bank	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
Right bank	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
SCORE (mean LB&RB) ___				
7. Riparian buffer (width)	Continuous parallel vegetation with dense groundcover or thick litter layer <u>and</u> all livestock excluded e.g. fully fenced	Mostly continuous vegetation with moderate grass cover or medium litter layer <u>and</u> limited stock access or human impacts e.g. single-wire fence and/or vegetation barrier	Grazed grass or sparse litter layer <u>and</u> pathways present for stock access to stream at watering points e.g. unfenced but may have vegetation barrier	Bare ground with high soil compaction <u>or</u> uncontrolled stock access or human impact obvious
	<u>and</u>	*<u>and</u>*	*<u>and</u>*	*<u>and</u>*
	Wide (>15m)	Moderate (>5m)	Narrow (<5m)	Absent or infrequent
Example score	*20 = <u>fully fenced</u>, mature and dense veg >20m wide, 19 = 20m wide, 18 = 15m wide est veg, 17 = 15m wide recently planted/fenced, 16 = 15m fenced but no new veg*	*15 = 10m wide <u>potentially not permanent fence</u>, mixed stage veg, 14 = 10m wide new planting, 13 = 8m wide mix veg, 12 = 5m wide mix veg, 11 = 5m wide new veg*	*10 = 5m wide <u>unfenced</u> but dense mix veg, 9 = 4m wide mix veg, 8 = 4m wide scattered veg, 7 = 3m wide scattered veg, 6 = 2m wide scattered veg*	*5 = <u>unfenced</u> some scattered large veg mainly grass, 4 = grazed grass, 3 = regular watering hole for stock, 2 = bare gound, 1 = impervious or highly modified streamside zone*
Left bank	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
Right bank	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
SCORE (mean LB&RB) ___				
8. Riparian shade	Vegetation (or banks) provide substantial shading of wetted width at baseflow (>70%)	Moderate shade (40-70%)	Minimal shade (10-40%)	Little or no shading of wetted width at baseflow (<10%)

Example score	*20 = ≥ 90% average canopy cover throughout day, 19 = 90%, 18 = 85%, 17 =80%, 16 = 75%*	*15 = 70%, 14 = 65%, 13 = 60%, 12 = 55% 11 = 50%*	*10 = 40%, 9 = 35%, 8 = 25%, 7 = 20%, 6 = 15%*	*5 = 10%, 4 = 8%, 3 = 6%, 2 = 4% 1 = 0%*
SCORE ___	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
9. Channel alteration	Natural streambed and bank form unmodified	Natural streambed, some evidence of bank stabilisation (e.g. near bridges). No instream structures or embankments alter natural flows.	Significant proportion of streambed or banks altered by man-made materials (e.g. concrete lining, wooden boxing, riprap or gabion baskets). Or embankments constrain major floods within channel	Streambed or banks altered over most of their length or natural flows significantly altered by instream structures (e.g. weirs, culverts) or embankments.
	or	*or*	*or*	*or*
	Stream with natural channel profile and sinuosity	<20% of channel length straightened, widened or deepened	20-50% of channel length straightened, widened or deepened	>50% of channel length straightened, widened or deepened
Example score	*20 = unmodified bed, bank, sinuosity, 16 = evidence of historical channel straightening but mainly unmodified*	*15 = natural in stream substrate some man-made bank materials up to 5% channel alteration, 11 = 15% alteration*	*10 = 20% channel alteration, 20% in stream/bank man-made materials, 6 = 50% channel alteration, 50% in stream/bank man-made materials*	*5 = 60% channel alteration 60% bank dominated by man-made materials, 1 = ≥75% channel altered ≥75% man-made structures*
SCORE ___	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1**
TOTAL (sum 1 to 9) ___				