



Riparian rehabilitation to improve aquatic environments in the Wellington region

Results from the riparian management pilot programme, 2002-07

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Executive summary

This report presents the monitoring results from Greater Wellington Regional Council's riparian management pilot programme, covering the period 2002 to 2007. Monitoring has included regular assessments of physical habitat, water quality and stream health along reaches of the Enaki, Kakariki and Karori streams undergoing riparian rehabilitation.

Despite the relatively young age of the riparian rehabilitation programme, a number of benefits are already apparent. The improvements observed for each of the three study streams vary and reflect the different stream types and land use impacts in the upstream catchments. The principal benefits attributable to riparian rehabilitation observed during the report period were:

- improved aesthetic values (Enaki, Kakariki and Karori streams);
- increased vegetation cover and streambed shade (Enaki and Kakariki streams);
- increased bank stability (Enaki and Kakariki streams);
- improved aquatic habitat quality (Enaki and Kakariki streams); and
- reduced water temperatures (Enaki and Kakariki streams).

Other benefits were observed at some sites, such as reduced instream plant growth (Enaki and Kakariki streams), lower nutrient concentrations and sediment inputs (Enaki Stream) and positive changes in macroinvertebrate (Enaki and Kakariki streams) and fish communities (Kakariki Stream). However, it was not always clear whether the observed improvements were directly linked with the rehabilitating riparian zones or caused by other factors. Nor was it clear in all cases whether these observed improvements resulted in any significant benefit to the overall health of the stream ecosystem.

Despite the observed benefits, the streams all remain in a degraded state; concentrations of nutrients and faecal indicator bacteria are elevated and the invertebrate and fish communities are dominated by species tolerant of degraded habitat and water quality. Even though the full benefits of riparian rehabilitation along reaches of the Enaki, Kakariki and Karori streams will not become apparent until riparian vegetation matures and canopy closure is achieved, the potential benefits that can be expected from riparian rehabilitation in the future are likely to be limited as all three stream reaches are strongly affected by the overriding impact of agricultural and urban land use within the upstream catchments (e.g., stock access to stream beds, effluent run-off, urban stormwater). For this reason, together with a number of limitations identified in the existing monitoring programme, it is appropriate to reduce some of the monitoring and focus more attention on addressing the issues limiting improvements.

This study has demonstrated that riparian rehabilitation can, in some situations, be a useful tool for mitigating some of the degradation caused by agricultural and urban land use to stream health in the Wellington region. However, it is clear that riparian rehabilitation alone will not address all the issues relating to poor stream health and that further plans and policies need to be developed and implemented, in conjunction with Greater Wellington's Riparian Management Strategy, to address the causes for poor stream health (e.g., farming practices and stormwater management).

Recommendations

1. Enaki Stream – continue the existing monitoring regime at the monitoring site located within the rehabilitation reach, but cease all monitoring of the upstream reach.
2. Kakariki Stream – continue with the existing biological monitoring at the site located within the rehabilitation reach, but cease all other monitoring.
3. Karori Stream – utilise monitoring data collected under Greater Wellington's Rivers State of Environment monitoring programme to assess the benefits of riparian rehabilitation in the future.

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1. Introduction

Riparian rehabilitation has become widely recognised as a way of improving aquatic ecosystem values of small streams. However, scientific documentation of regionally relevant studies that look at the changes that occur in stream ecosystems as rehabilitation is carried out is limited.

In order to provide some baseline information for Greater Wellington Regional Council's (Greater Wellington) Riparian Management Strategy (2003) a riparian management pilot programme was established in 2001. This programme involves rehabilitation and monitoring of reaches of three streams in the region; the Enaki Stream in the Wairarapa, the Karori Stream in Wellington City and the Kakariki Stream on the Kapiti Coast (Figure 1.1). Monitoring of riparian margins and stream health began in January 2002. The primary aim of this monitoring is to document the effects of riparian rehabilitation on stream ecosystems with particular focus on the first three environmental outcomes listed in the Riparian Management Strategy relating to water quality, aquatic habitat and healthier river ecosystems.

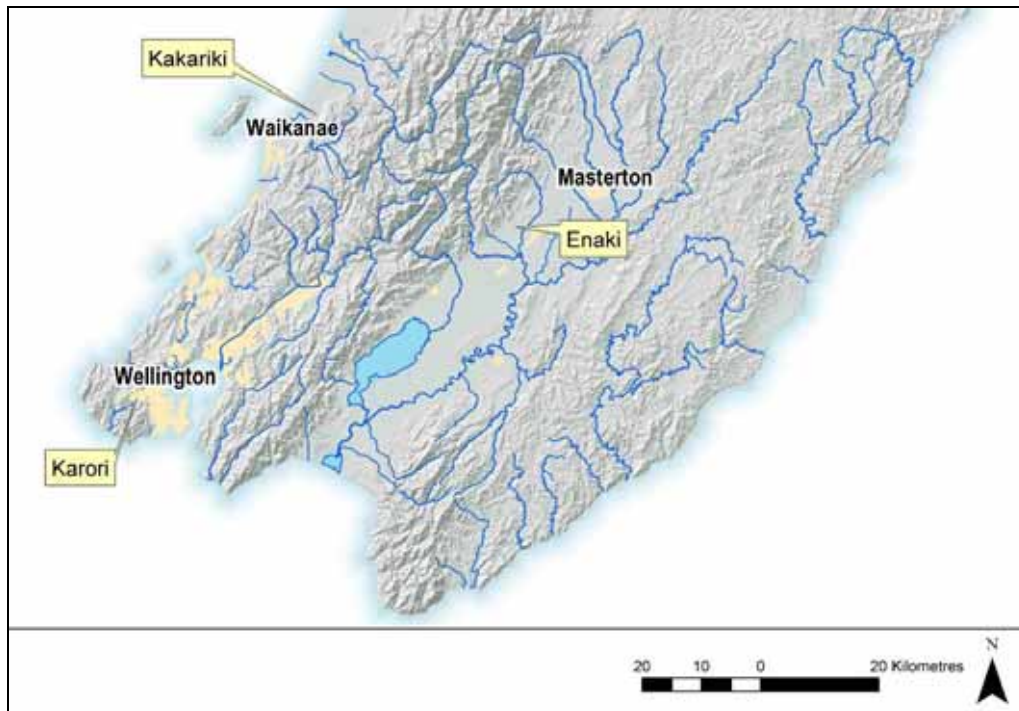


Figure 1.1: Locations of the three streams included in the riparian rehabilitation monitoring programme.

This report follows on from a preliminary monitoring report (Warr 2004), and documents the results of the monitoring programme for the period 2002 to 2007. Recommendations for future monitoring are also provided.

1.1 Report outline

This report comprises seven sections. The second section provides an overview of the benefits of riparian rehabilitation as well as the anticipated benefits of riparian rehabilitation for each of the three study stream reaches. Details of the

methods, assessments and analysis used in monitoring riparian margins, water quality and stream health in this report are in section three. Section four includes an overview of the Enaki Stream riparian rehabilitation programme, presents the results and assessments from the monitoring programme and provides interpretation and discussion of these results. Sections five and six follow the same structure as section four for the Kakariki and Karori streams respectively. Section seven summarises the key findings across all three study streams and includes recommendations for future monitoring.

2. The benefits of riparian rehabilitation

Agricultural and urban land use have been shown to have detrimental impacts on water quality and aquatic communities throughout the Wellington region (e.g., Milne & Perrie 2005, Warr 2007, Perrie 2007a). Riparian rehabilitation is seen as a tool to help mitigate these impacts.

The riparian zone, strip or area can be defined as “any land that adjoins or directly influences, or is influenced by, a body of water” (Ministry for the Environment 2000). The function of riparian zones in buffering (reducing) the effects of land use on water quality and instream ecosystems are well documented in the literature.

Pollutants such as nutrients, faecal bacteria and sediments, have a wide range of detrimental impacts on aquatic ecosystems and can enter streams directly through stock access to the streambed, effluent discharge or surface runoff, or indirectly by subsurface flow (Parkyn 2004). Increases in nutrient concentrations (nitrogen and phosphorus) can, in certain conditions, lead to nuisance growths of algae and aquatic plants which can in turn reduce water quality, decrease habitat quality and diversity, inhibit the normal flow regime and reduce the overall aesthetic value of the waterway. Elevated levels of faecal bacteria can make the water unsuitable for recreational activities, food gathering and stock water supply.

Suspended sediment reduces water clarity which reduces light penetration for primary production, and can impact on sighted animals. It can also cause physical abrasion of periphyton, invertebrates and fish. Sediments that settle out of the water column can fill interstitial spaces that affect habitat availability for invertebrates and fish (Ryan 1991). Increases in the proportion of silt cover on the stream bed have been linked with changes in invertebrate community structure in New Zealand streams (Quinn & Hickey 1990).

Management of riparian zones can help reduce the impacts of pollutants on stream ecosystems. Fencing off and planting of riparian zones can greatly reduce the volume of pollutants that enter a stream and can have immediate benefits to the aquatic ecosystem (Parkyn 2003). Stock have been shown to be 50 times more likely to defecate while in a stream than elsewhere and access to the streambed is associated with high concentrations of nutrients, suspended solids and faecal bacteria (Davies-Colley et al. 2004). In addition to adverse effects on water quality, stock access is known to negatively affect stream channel morphology, hydrology, riparian zone soils, instream and stream bank vegetation, and aquatic and terrestrial wildlife (Belsky et al. 1999).

Vegetated riparian buffer zones can intercept surface transport of pollutants by reducing surface flow velocities leading to enhanced deposition of particles and by improving infiltration of soluble pollutants within the soil's of the riparian buffer zone (Gharabaghi et al. 2002); soluble nutrients can then be taken up by streamside plants before they reach the stream (Schipper et al. 1991). Riparian buffer zones can considerably reduce inputs of suspended solids, nutrients (Murgatroyd & Ternan 1994) and faecal bacteria (Larsen et al. 1994). In one New Zealand study, retired grass buffer zones reduced concentrations of

suspended sediments, nitrite-nitrate nitrogen and dissolved reactive phosphorus in surface runoff by 80 %, 67 % and 55 % respectively (Smith 1989).

Subsurface pollutant transport can be reduced by interception and uptake by stream-side vegetation and by denitrification. Denitrification is the process by which nitrate is converted by microbial action to nitrogen gas, and effectively leaves the system. Riparian buffer zones have been shown to reduce nitrate concentrations in subsurface flows by up to 90 % (Fennesey & Cronk 1997) if environmental conditions are right (wet soils with long residence times).

As well as intercepting pollutants, the increase in shade provided by riparian planting can help control nuisance growths of periphyton and macrophytes. The water and habitat changes caused by extensive algal cover can result in major shifts in stream invertebrate community structure (Biggs 2000). A reduction in light levels has been correlated with lower algal biomass in some New Zealand streams (Quinn et al. 1992).

The thermal regime of a stream is an important factor in determining ecosystem structure and function and streambed shade produced by riparian vegetation can play a significant role in controlling water temperature. Upper thermal tolerances for sensitive stream invertebrates and fish species have been conservatively estimated at 20°C (Rutherford et al. 1999) and 26°C (Simons 1986) respectively. Routine monitoring of water temperatures within the Wellington region shows that many river and stream temperatures can regularly exceed 20°C (e.g., Perrie 2007b). The increased streambed shade provided by riparian plants can reduce the frequency of these exceedances. Shade levels required to reduce water temperatures depend on many factors (stream size, buffer length, etc.) and it can take many years after planting riparian vegetation for a significant reduction in temperature to occur (Parkyn et al. 2003).

Riparian vegetation can increase the input of woody debris into a stream and in doing so improves habitat quality as woody debris is an important substrate for sensitive invertebrate species (Stark et al. 2001). In addition, cover provided by woody debris is a key habitat feature for native fish species, especially large galaxiids (Hanchet 1990). However, it can take many decades to centuries for significant quantities of woody debris to accumulate in streams (Parkyn et al. 2003).

Riparian vegetation also provides habitat for the terrestrial adult life stages of aquatic insects (Smith & Collier 2000); these insects in turn are important food items for a number of native fish species (McDowall 1990). Furthermore, leaf inputs are an important food source for stream invertebrates (Linklater & Winterbourn 1993). Additionally, stream-side vegetation has been shown to be an important spawning medium for many fish species (McDowall 1990); and adds to the overall habitat diversity (e.g., overhanging vegetation).

Despite the numerous benefits riparian rehabilitation can have it is important to realise that even a well planted stream margin cannot replicate an entire forested catchment. However, riparian rehabilitation is an extremely useful tool

that has the potential to mitigate land use effects and to help improve some aspects of stream water quality and ecosystem health.

2.1 Anticipated benefits for each study stream reach

The potential benefits of riparian rehabilitation for each stream were assessed and classified using the system outlined by Quinn et al. (2001). This system uses the landform attributes of the site to determine the potential biogeophysical roles and human uses of the riparian area. By comparing these to the current riparian functions the potential benefits of riparian rehabilitation can be assessed. The current and potential functions are ranked as: 0 (absent), 1 (very low activity), 2 (low-moderate activity), 3 (moderate activity), 4 (high activity) or 5 (very high activity). These assessments were carried out along each stream reach prior to the commencement of riparian rehabilitation in 2001.

2.1.1 Enaki Stream

The current (pre-rehabilitation), potential and anticipated benefits of riparian rehabilitation for the Enaki Stream are summarised in Table 2.1. Principal benefits that could be achieved include:

- improved bank stability;
- increased stream shade for water temperature and aquatic plant control;
- improved aquatic habitat (woody debris input and overhanging vegetation);
- reduced nutrient, faecal bacteria and sediment input (stock exclusion and nutrient uptake from groundwater); and
- improved aesthetic value.

2.1.2 Kakariki Stream

The main improvements expected of riparian rehabilitation for the Kakariki Stream are (Table 2.1):

- improved bank stability;
- increased stream shade for water temperature and aquatic plant control;
- improved aquatic habitat (woody debris input and overhanging vegetation);
- reduced nutrient, faecal bacteria and sediment input (stock exclusion, improved filtering of overland flow, nutrient uptake from groundwater and denitrification); and
- improved aesthetic value.

2.1.3 Karori Stream

The principal benefits of riparian rehabilitation in the Karori Stream (Table 2.1) include:

- increased stream shade for water temperature and aquatic plant control;
- improved aquatic habitat (woody debris input and overhanging vegetation); and
- improved aesthetic value.

Table 2.1: Comparison of the pre-rehabilitation and potential (i.e., following riparian rehabilitation) functions and values of the riparian margin for the Enaki, Kakariki and Karori Streams., based on an assessment carried out in 2001 using the methodology outlined in Quinn et al. (2001). The anticipated benefits from riparian rehabilitation (i.e., the current score for each value or function subtracted from the potential score) are also shown.

Functions and uses	Enaki Stream			Kakariki Stream			Karori Stream		
	Pre-rehabilitation	Potential	Anticipated benefits	Pre-rehabilitation	Potential	Anticipated benefits	Pre-rehabilitation	Potential	Anticipated benefits
Stream bank stability	2	5	3	1	5	4	4	4	0
Filtering overland flow	2	2	0	0	3	3	4	4	0
Fish spawning/habitat/cover	1	2	1	0	4	4	2	2	0
Shade for instream temperature control	2	4	2	1	3	2	3	5	2
Shade for instream plant control	2	5	3	2	4	2	2	4	2
Woody debris input	1	3	2	0	4	4	2	4	2
Plant nutrient uptake from groundwater	1	2	1	1	2	1	4	4	0
Denitrification nitrogen control	1	1	0	0	1	1	1	1	0
Direct animal waste control	1	2	1	1	5	4	1	1	0
Downstream flood control	2	2	0	2	2	0	1	1	0
Recreation	1	1	0	0	2	2	2	2	0
Aesthetics	1	5	4	0	5	5	2	5	3

3. Methods

3.1 Physical habitat assessment

Physical habitats assessments of all three streams were carried out on two occasions, during April and May 2003 (see Warr 2004 for results) and October and November 2007. Physical stream habitat was assessed over 100 m reaches at each site. Within each reach assessments were made of vegetation cover and stream shade as well as channel and instream characteristics. These assessments were made along five equally spaced transects within each 100 m reach.

3.1.1 Vegetation and shade

Percentage cover of vegetation less than 0.5 m, between 0.5 and 5 m and greater than 5 m tall was visually assessed on each bank at each of the five transects. The dominant vegetation type and number of plantings were also noted within 0.5 m either side of each transect.

Stream shade was estimated visually using an inclinometer. Using this instrument the angle from the observer in the middle of the stream to the top of the stream bank and to the top of the streamside vegetation or topography was estimated at eight points of the compass. Along with estimates of vegetation density these angles were used to estimate the shading of the streambed from vegetation and topography.

Rutherford et al. (2004) found that a similar visual shade assessment method had an average uncertainty of $\pm 10\%$ and consistently overestimated the canopy gap fraction (i.e., underestimated shading). Despite these limitations, it was decided that this method would provide an adequate means of comparison of stream shade between sites and over time.

3.1.2 Channel characteristics

Channel characteristics were assessed along five transects, 20 m apart within each 100 m reach. At each transect a tape measure was stretched across the width of the stream and the riparian margins. The channel profile was estimated by measuring the distance between the tape measure and the substrate with a graduated staff gauge.

The stream profiles were used to assess water level, mid bank and bank full stream width as well as bank height. Maximum water depth was measured at each transect.

Bank and channel stability was estimated over the 100 m stretch using the Pfankuch method as outlined in Collier (1992). The Pfankuch method scores physical variables (weighted according to perceived importance) of the upper bank, lower bank and channel bed. These measures are then summed to generate an overall rating of bank stability.

3.1.3 Instream characteristics

Along each of the five transects a number of instream characteristics were recorded. Percentage cover of the substrate size classes identified in Wolman (1954) was estimated at five points along each transect. Percentage cover of woody debris and macrophytes were also estimated. Overhanging vegetation was measured using a graduated staff gauge.

3.1.4 Approach to analysis

Physical habitat data were recorded and analysed in Microsoft Excel. The results from the habitat assessments were visually compared between sites upstream of and within the rehabilitation area of each stream. In some cases, where available and appropriate, data from reference sites are also presented. Comparisons with earlier habitat assessments carried out in 2003 (Warr 2004) are also made where applicable. However, it is important to note that transect locations used in habitat assessments in 2003 were not necessarily the same as those used in 2007. This could potentially account for some variation between assessments. In addition, there is a certain level of subjectivity in the methodology of some assessments (e.g., assessing Pfankuch scores) that could result in differences between assessments.

3.2 Water quality

Water quality was assessed at monthly intervals by measuring a range of physico-chemical and microbiological variables: dissolved oxygen, temperature, pH, conductivity, turbidity, suspended solids, faecal indicator bacteria, total organic carbon, and dissolved and total nutrients. A full list of variables monitored, together with details of field and analytical methods is provided in Appendix 1. Flow gaugings were taken each month at the time of sampling to enable flow adjustment¹ of water quality results for long term trend analysis.

In addition, water temperature was monitored continuously each year during summer and autumn using stowaway tidbit® temperature loggers.

3.2.1 Approach to data analysis

Water quality data used in the analyses in this report incorporate the period January 2002 to December 2006 (inclusive). Continuous water temperature data presented in this report were collected during January and February of 2007, except in the case of the Enaki Stream (February 2006)².

During data processing, any water quality variables reported as less than or greater than detection limits were replaced by values one half of the detection limit or the detection limit respectively (e.g., a value of < 2 became 1).

¹ Many water quality variables are influenced by flow. Flow adjustment removes the effects of flow that may obscure the detection of trends that are masked by variation in flow at the time of sampling.

² A stowaway tidbit® temperature logger was lost from the monitoring site within the rehabilitation area on the Enaki Stream in 2007, thus upstream and downstream comparisons of water temperature could not be made for this year.

Key physico-chemical and microbiological variables were summarised and compared against appropriate national water quality guidelines (see Appendix 2) to provide an overview of water quality at each stream monitoring site. Comparisons between monitoring sites upstream of and within the rehabilitation area were carried out using the non-parametric Wilcoxon Matched Pairs Test in SYSTAT (version 10). Differences in monitored parameters between sites were deemed to be statistically significant if the *p* value was less than 0.05 (i.e., there is less than a 5 % chance that the difference between sites is caused by chance).

Temporal trends were analysed in WQ Stat Plus (version 1.5) using the Seasonal Kendall Trend Test. Trend analyses were performed on both raw and flow-adjusted data. A trend was deemed to be statistically significant if the *p* value was less than 0.05.

3.3 Biological monitoring

Monitoring of aquatic communities (periphyton, invertebrates and fish) was undertaken to measure ecosystem health.

3.3.1 Periphyton

Nuisance periphyton cover was assessed on a monthly basis using the RAM-1 method and periphyton biomass was assessed annually during summer/autumn months using method QM1-a followed by analysis for chlorophyll *a* concentration (Biggs & Kilroy 2000).

Periphyton was not assessed at the Kakariki Stream site due to the soft bottomed substrate.

3.3.2 Macroinvertebrates

Benthic macroinvertebrates were sampled annually during summer/autumn using protocols C1 (at the Enaki and Karori Streams) and C2 (at the Kakariki Stream) outlined in Stark et al. (2001). Three replicate samples were taken at each site with each sample comprising 5 and 10 sub-samples for cobble and silt bottomed sites respectively. Samples were preserved in 70 % isopropyl alcohol and processed using method P1 outlined in Stark et al. (2001).

3.3.3 Fish

All sites were fished in 2002, 2003 and in 2007 using single pass electrofishing. Each site was fished over a reach of at least 100 m including the full range of flow regimes and habitats within the reach. Fish were identified in the field and released. Abundance was estimated for each species and classed as either absent (0), rare (1 - 3), common (4 - 10), or abundant (10+).

Due to depth and sluggish flows, electrofishing was not the most suitable method for assessing the fish fauna in the Kakariki Stream. In 2007, minnow traps were used to supplement the information gathered by electrofishing. This involved setting ten 3 mm minnow traps within the rehabilitation area and ten traps within the upstream reach. Traps were left overnight and collected the

following day. As with electrofishing, fish were identified in the field, counted and released.

3.3.4 Approach to analysis

Periphyton streambed cover measurements recorded over January 2002 to December 2006 (inclusive) and periphyton biomass data (2002 to 2007 inclusive) were assessed against relevant guidelines in Biggs (2000).

Macroinvertebrate data from 2002 to 2007 (inclusive) are presented in this report. Invertebrate metrics (Macroinvertebrate Community Index (MCI) and its semi-quantitative equivalent (SQMCI)) are assessed against thresholds recommended by Stark & Maxted (2007). Additionally, the proportion of sensitive invertebrate species (Ephemeroptera, Plecoptera and Trichoptera³ (EPT taxa)) compared to total taxa richness were also calculated.

Linear trends in macroinvertebrate indices were examined using non-parametric Spearman rank correlations. Correlations were considered significant when p values were less than 0.05. There were too few data points for statistical examination of non-linear trends but any potential trends could be identified visually in the graphs.

Fish abundance was estimated from electrofishing results and classed as absent, rare, common and abundant. Relative abundances were compared visually between sites. The non-parametric Kruskal-Wallis Test was used to test for differences between the catch per unit effort (CPUE) results from the trapping carried out in the Kakariki Stream.

³ Excluding Oxyethira and Paroxyethira which are relatively tolerant of pollution.

4. Enaki Stream

4.1 Overview of Enaki catchment

The Enaki Stream drains a catchment of approximately 2,470 hectares and has its headwaters in the foothills of the Tararua Forest Park. The geology of the upper catchment is predominantly greywacke while the rest of the catchment comprises alluvial gravels, loess and sandstone/siltstone.

The headwaters area of the Enaki catchment is dominated by scrub. The rest of the catchment is dominated by pastoral farmland, much of which is used for dairying. The rehabilitation area is located at the bottom of the Enaki Stream catchment immediately before it flows into the Mangatarere Stream (Figure 4.1). This stretch of the Enaki Stream has an entrenched floodplain formation with a cobble bed and many areas incised due to erosion. Land use in the immediate vicinity of the rehabilitation area is dairying.

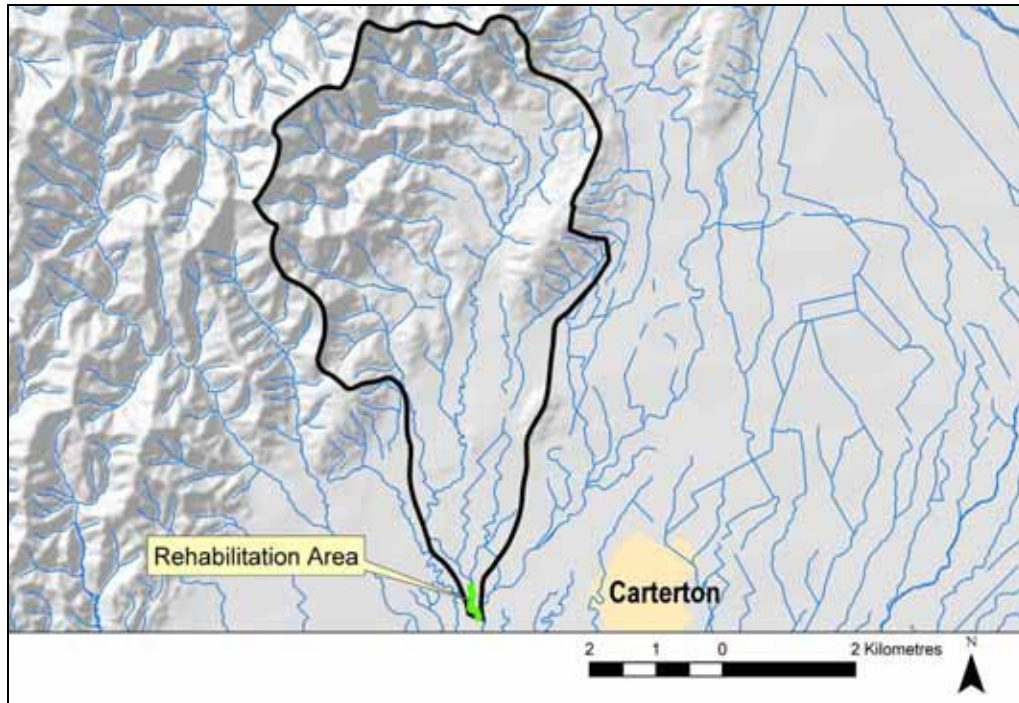


Figure 4.1: The Enaki Stream catchment showing the stretch of stream undergoing riparian rehabilitation.

Fencing and planting of a small number of poplars began in the rehabilitation area in 1999, followed by shrub willow in 2000 and a mixture of native trees and shrubs in 2001. The rehabilitation area shown in Figures 4.1 and 4.2 represent the original section of stream retired for riparian rehabilitation. Riparian rehabilitation has since occurred upstream of this area.

4.2 Monitoring sites

Monitoring was carried out at sites on the upstream and downstream boundaries of the rehabilitation area (Figure 4.2). This equates to approximately 600 m of stream length fenced off and planted between the two

sites. The site upstream of the rehabilitation area was monitored to provide results that represent pre-rehabilitation conditions (i.e., a control site); these results could then be compared with those collected from the downstream site (within the rehabilitation area) to determine the effects riparian rehabilitation is having on physical habitat, water quality and stream health.

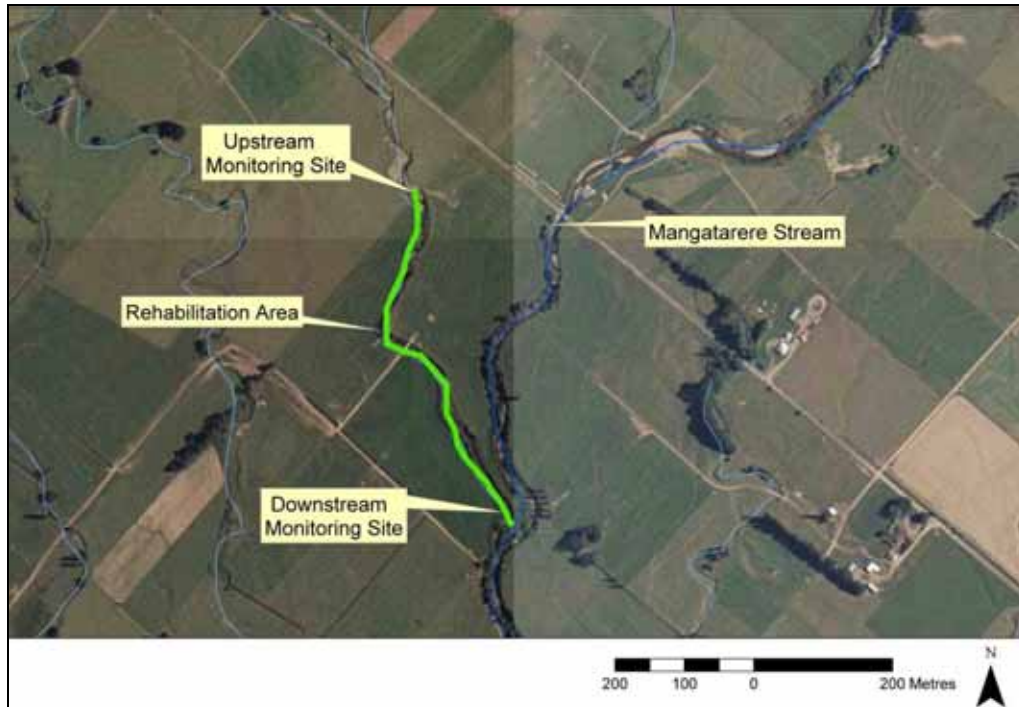


Figure 4.2: Enaki Stream and locations of the monitoring sites upstream of and within the rehabilitation area (downstream site).

4.3 Study limitations

In 2003, fencing and planting occurred immediately above the rehabilitation area⁴. This means that the upstream monitoring site is no longer representative of pre-rehabilitation (or control) conditions and will limit the value of comparisons between monitoring sites. However, because the rehabilitation area has been established for a longer period of time these comparisons have still been made.

4.4 Results

This section presents the results of a physical habitat assessment, physico-chemical and microbiological water quality monitoring, and biological assessments for sites upstream of and within the riparian rehabilitation area on the Enaki Stream. Where appropriate, comparisons with habitat assessments carried out in 2003 (Warr 2004) are presented.

⁴ In addition, as part of Greater Wellington's riparian strategy, over seven kilometres of the Enaki Stream and its tributaries have been fenced and planted over 2001 to 2004 (Bell 2007). This represents approximately 67 % of the total stream length of the Enaki Stream (that is suited to revegetation) and will also impact on the inter-site comparisons and some of the conclusions that can be drawn from this study.

4.4.1 Physical habitat assessment

(a) Vegetation and shade

Vegetation cover within the rehabilitation area of the Enaki Stream was significantly greater than that upstream (Figure 4.3). This was more evident in vegetation cover greater than 5 m high (Figure 4.4). Twelve percent cover was provided by vegetation in this height class within the rehabilitation area (consisting of willows and poplars), but there was 0 % cover upstream. Vegetation cover was also higher in the 0.5 m to 5 m height class within the rehabilitation area (32 %), while upstream this height class provided 25 % cover. Composition was similar between reaches for this height class and both sites were dominated by a mixture of broom, willows, poplars and a range of planted natives including flaxes, pittosporums and cabbage trees.



Figure 4.3: Sites upstream (top) of and within the rehabilitation area (downstream) of the Enaki Stream. Photos taken in 2003 and 2005 respectively.

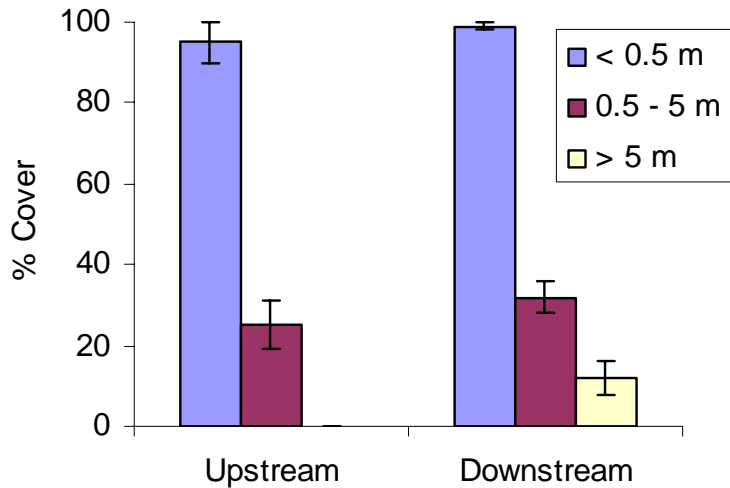


Figure 4.4: Percentage cover (± 1 standard error) of vegetation < 0.5 m, $0.5 - 5$ m and > 5 m tall on riparian margins upstream of and within the rehabilitation area (downstream) on the Enaki Stream.

In comparison to 2003, cover from vegetation taller than 5 m has increased within the rehabilitation area from 0.7 % to 12 %. Cover within the other two vegetation size classes remains similar to that estimated in 2003. At the upstream site, cover provided by vegetation between 0.5 m and 5 m tall has more than doubled, increasing from 12 % in 2003 to 25 % in 2007. On average, the number of native plantings counted along each transect was higher for the upstream reach (1.6 plants per transect) than within the rehabilitation reach (1 plant per transect).

The increase in vegetation cover also meant streambed shading was greater within the rehabilitation area than upstream; estimated at 30 % and 16 % respectively. Streambed shading has increased in both reaches since original estimates were made in 2003. The rehabilitation reach increased from 23 % in 2003 to 30 % in 2007 while the upstream reach saw a five-fold increase from just 3 % in 2003 to 16 % in 2007.

(b) Channel characteristics

Average channel dimensions are summarised in Table 4.1. As previously reported by Warr (2004), the stream channel within the rehabilitation area tended to be narrower and more incised than upstream. Bank full width within the rehabilitation area was on average 34 % less than that upstream and bank height 29 % greater. Maximum water depth within the rehabilitation area was similar to that upstream (0.33 and 0.37 m respectively).

Table 4.1: Average channel dimensions (m) upstream of and within the rehabilitation area (downstream) of the Enaki Stream.

Site	Water level width	Mid bank width	Bank full width	Bank height	Max depth
Upstream	6.22	10.16	13.82	1.52	0.37
Downstream	4.11	8.12	9.64	2.14	0.33

Pfankuch scores indicate that bank stability was better within the rehabilitation area than upstream, but both sites had overall ratings of fair.

(c) Instream characteristics

There was little difference in substrate size between the rehabilitation reach and the upstream reach with large and small gravels dominating in both cases (Figure 4.5). In 2003, a higher proportion of silt was found upstream (18 %) than within the rehabilitation area (0 %); this was not observed in 2007 (~ 5 % silt cover in both reaches).

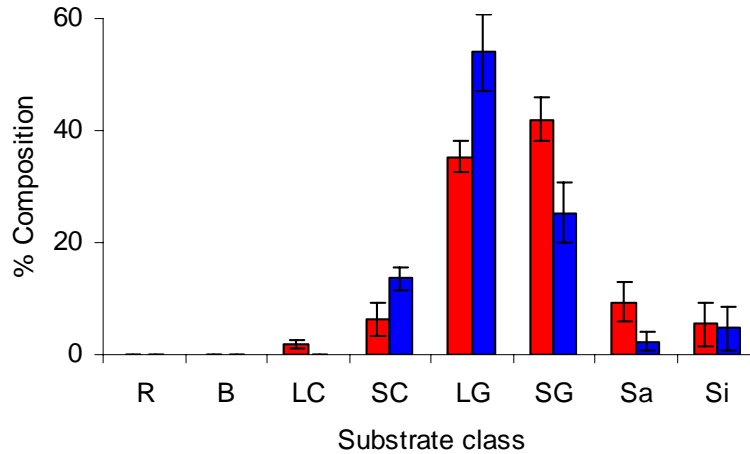


Figure 4.5: Average percent composition (± 1 standard error) of substrate size classes upstream (red) of and within the rehabilitation area (downstream – blue) on the Enaki Stream. R = bedrock, B = boulders (> 256 mm), LC = large cobbles (128 - 256 mm), SC = small cobbles (64 – 128 mm), LG = large gravel (16 – 64 mm), SG = small gravel (2 - 16 mm), Sa = sand, Si = silt

More overhanging vegetation was present upstream than within the rehabilitation area although the upstream average cover value was heavily influenced by one transect that included an overhanging willow (2 m from the true left bank). Woody debris and macrophyte cover were minimal (less than 2 %) at both sites (Table 4.2). Estimates of woody debris and macrophyte cover were both lower in 2007 than in 2003, with the latter noticeably so; previously macrophyte cover was recorded at around 17 % both within the rehabilitation area and upstream.

Table 4.2: Instream characteristics upstream and within the rehabilitation area (downstream) of the Enaki Stream.

Site	Overhanging vegetation (m)	Woody debris (% cover)	Macrophyte (% cover)
Upstream	0.27	2	1
Downstream	0.17	1	1

4.4.2 Water quality

A summary of monthly water quality data collected during January 2002 and December 2006 is shown in Table 4.3. Median concentrations of dissolved and total nutrients and *E. coli* bacteria are well above national (ANZECC 2000) water quality guidelines for lowland streams (see Appendix 2).

Table 4.3: Summary of physico-chemical and microbiological water quality data, based on monthly monitoring over January 2002 to December 2006 for the Enaki Stream, upstream of and within the rehabilitation area (downstream). Statistically significant differences ($p < 0.05$) between median values are shown in bold font.

Variable	Upstream				Downstream			
	Median	Min	Max	<i>n</i>	Median	Min	Max	<i>n</i>
Temperature (°C)	13.8	6.5	25.7	57	13.8	6.18	25.7	56
Dissolved Oxygen (% saturation)	96	79.9	142	55	93	71.4	114	54
Dissolved Oxygen (g/m ³)	10.2	6.0	13.9	55	9.6	5.8	12.39	54
pH	7.00	5.1	7.7	48	6.94	5.11	8.58	50
Turbidity (NTU)	2.60	0.2	100	58	2.55	0.25	95	58
Total Suspended Solids (g/m ³)	3	1.5	146	58	1.5	1.5	155	58
Conductivity (µS/cm)	117	88	183	54	115	73	188	55
Total Organic Carbon (g/m ³)	2.35	0.25	10.2	58	1.95	0.6	9.6	58
Nitrite-Nitrate Nitrogen	1.155	0.192	2.7	56	1.125	0.136	2.75	56
Ammoniacal Nitrogen (g/m ³)	0.02	0.005	0.17	58	0.01	0.003	0.07	58
Total Kjeldahl Nitrogen (g/m ³)	0.3	0.1	2.6	58	0.3	0.1	1	58
Total Nitrogen (g/m ³)	1.75	0.4	3.4	58	1.70	0.3	3.1	57
Dissolved React. Phosphorus (g/m ³)	0.025	0.002	0.047	58	0.026	0.005	0.054	57
Total Phosphorus (g/m ³)	0.045	0.015	0.227	58	0.041	0.014	0.23	58
<i>E. coli</i> (cfu/100mL)	207	5	26,300	57	190	20	31,333	57

Analysis of median water quality results from the rehabilitation area and the upstream site showed statistically significant differences ($p < 0.05$) in temperature (continuous monitoring, but not monthly measurements), turbidity, pH, dissolved oxygen, total organic carbon, total nitrogen, and total phosphorus, all of which were lower within the rehabilitation area (Table 4.3). Some of these differences were apparent very early on in the monitoring programme as reported by Warr (2004). Full details of the analysis are in Appendix 3.

Continuous water temperature measurements made during the summer months showed a statistically significant ($p < 0.05$) decrease within the rehabilitation area. For example, during a period in February 2006, mean daily temperatures were 0.8 °C lower and maximum temperatures were 2.5 °C lower (Figure 4.6). Dissolved oxygen concentrations and percent saturation levels were 0.6 g/m³ and 3 % lower respectively within the rehabilitation area and total nitrogen and total phosphorus concentrations were 0.05 and 0.004 g/m³ lower respectively.

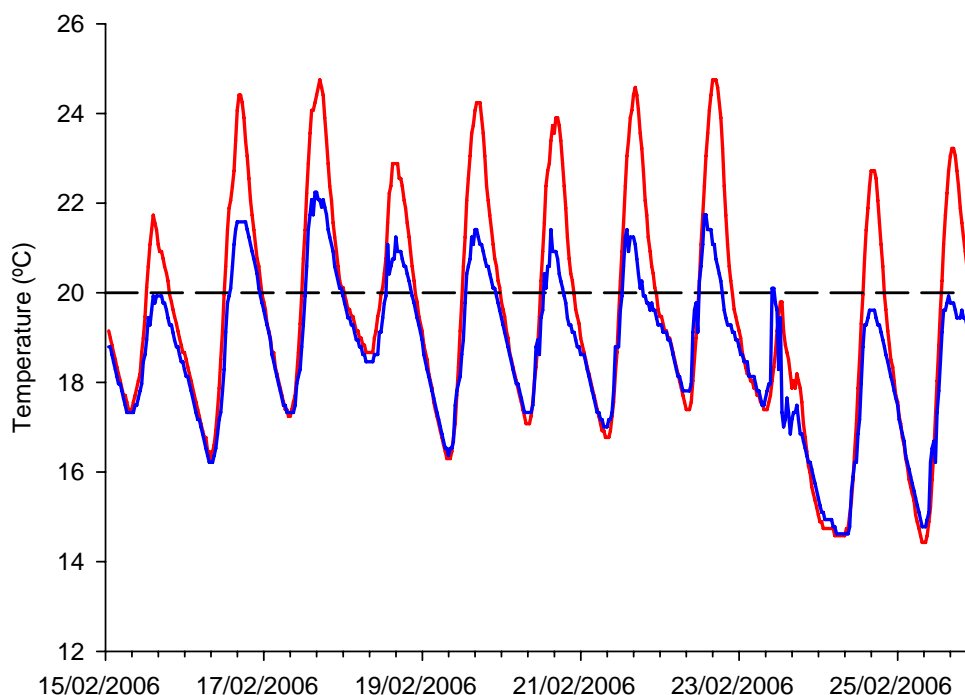


Figure 4.6: Water temperature at sites upstream (red) of and within the rehabilitation area (downstream – blue) on the Enaki Stream, based on continuous monitoring between 1 February and 25 February 2006. The dashed line represents the upper thermal tolerance for sensitive invertebrate species (Rutherford et al. 1999).

Statistically significant ($p < 0.05$) trends from Seasonal Kendall trend analysis are summarised in Table 4.4. Full details are located in Appendix 4. Monthly water temperature measurements decreased within the rehabilitation area by about 0.8 °C per year (Figure 4.7), with a similar magnitude trend observed upstream. Stream pH decreased by about 0.15 pH units per year within the rehabilitation area and by about 0.11 pH units per year upstream. Decreases in dissolved oxygen saturation were around 2 % per year upstream of the rehabilitation area and approximately 1.6 % per year within it (trend was only present in flow-adjusted data). At the upstream site, total phosphorus concentrations decreased by around 0.004 g/m³ per year during the reporting period. A similar but smaller trend was observed within the rehabilitation area, 0.003 g/m³ and 0.0004 g/m³ per year for raw and flow-adjusted data respectively.

Table 4.4: Trend slopes (units per year) for selected raw and flow-adjusted water quality variables that exhibited statistically significant trends ($p < 0.05$) at sites upstream of and within the rehabilitation area (downstream) on the Enaki Stream over January 2002 to December 2006. NS denotes non-significant (i.e., no trend).

Variable	Upstream		Downstream	
	Raw	Flow-adjusted	Raw	Flow-adjusted
Temperature (°C)	-0.788	-0.7371	-0.6384	-0.7587
pH	-0.1097	-0.1206	-0.1441	-0.1514
Dissolved Oxygen (% saturation)	-1.939	-2.033	NS	-1.571
Total Phosphorus (g/m ³)	-0.003723	-0.004099	-0.00331	-0.0003734

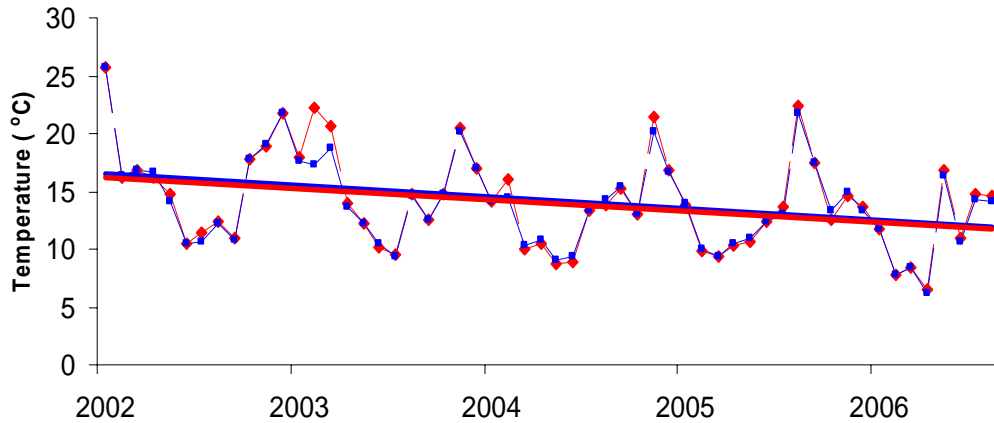


Figure 4.7: Monthly water temperature measurements recorded upstream (red) of and within the rehabilitation area (downstream – blue) of the Enaki Stream over January 2002 to December 2006. The solid lines represent the overall trends.

4.4.3 Biological monitoring

(a) Periphyton

Based on one-off annual measurements, periphyton biomass (as indicated by chlorophyll *a* concentrations) was typically much higher at the upstream site than within the rehabilitation area. This was especially apparent in 2003 (Figure 4.8). On only one occasion was the downstream concentration higher (2006), and then the difference was not great; 45.3 mg/m² upstream compared to 51.0 mg/m² downstream.⁵

The highest chlorophyll *a* concentrations were recorded at both sites in 2003 (92.3 mg/m² within the rehabilitation area and 801.4 mg/m² upstream) when both sites exceeded MfE (2000) guidelines for benthic invertebrate biodiversity (maximum chlorophyll *a* < 50 mg/m²). In 2006 the rehabilitation site narrowly exceeded the guideline value again.

Monthly visual estimates of periphyton streambed cover showed more nuisance filamentous periphyton (> 2 cm in length) upstream of the rehabilitation area. Of the 52 observations made during the reporting period, the upstream site recorded growths of filamentous periphyton on 12 occasions and on three of these exceeded MfE (2000) guidelines for recreation/trout angling (> 30 % cover). Filamentous periphyton cover was recorded on just four occasions within the rehabilitation area and was always within guideline values.

⁵ The higher biomass within the rehabilitation area in 2006 may well be related to the removal of crack willow in December of 2005 from the immediate surrounding area of the sampling site; while not estimated at the time there was a noticeable decrease in stream bed shade as a result.

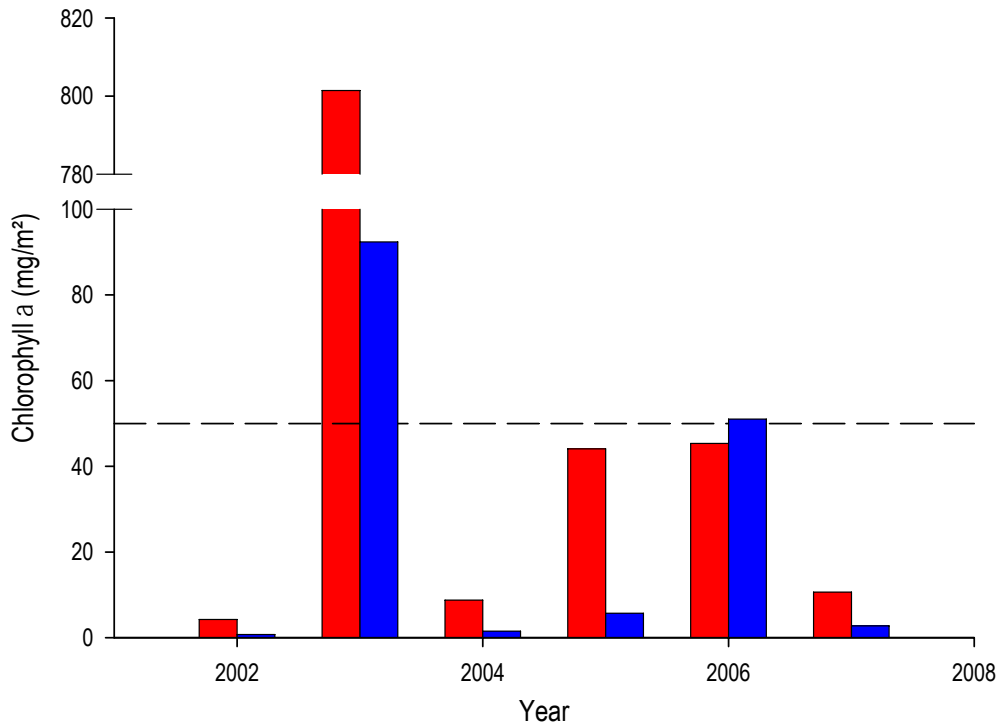


Figure 4.8: Periphyton chlorophyll a concentrations measured upstream (red) of and within the rehabilitation area (downstream – blue) of the Enaki Stream for 2002 to 2007. Concentrations are based on one-off samples collected annually during the summer months. Note the break on the y-axis. The black dashed line indicates the MfE (2000) threshold for the protection of benthic biodiversity (50 mg/m²).

(b) Invertebrates

There was a tendency for measures of invertebrate community health (MCI, SQMCI and % EPT taxa) to be slightly higher within the rehabilitation area; however, these differences were normally of a small magnitude. The monitoring results from 2003 were the exception; in 2003, all measures of invertebrate community health were much higher within the rehabilitation area (e.g., the MCI value was 119.1 compared with 86.1 upstream).

Based on thresholds recommended by Stark & Maxted (2007), invertebrate community health at both sites has fluctuated between poor and excellent over the reporting period. Overall, invertebrate community health upstream of and within the rehabilitation area can probably be classed as ‘good’ (Table 4.5).

No linear trends were detected in any of the invertebrate metrics examined for either site over the reporting period (full details of analysis can be found in Appendix 5). This is illustrated in Figure 4.9, where (apart from 2003 for the upstream site) MCI values, while fluctuating year to year, remained relatively steady over the reporting period; a similar pattern was observed in the SQMCI and % EPT taxa metrics.

Table 4.5: Measures of invertebrate health (MCI, SQMCI, and % EPT taxa) for the Enaki Stream upstream of and within the rehabilitation area (downstream), based on annual monitoring over 2002 to 2007. The 2002 scores are based on just one sample, mean score and standard deviation (SD) for all other years are based on three replicate samples.

Year	MCI				SQMCI				% EPT (taxa)			
	Upstream		Downstream		Upstream		Downstream		Upstream		Downstream	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2002	98.7	-	108.3	-	5.8	-	6.1	-	33.3	-	41.7	-
2003	86.1	3.7	119.1	6.7	3.3	0.3	5.4	0.2	30.7	9.3	51.3	7.5
2004	120.5	4.0	120.4	3.5	6.9	0.4	6.6	0	54.9	3.0	57.9	7.1
2005	108.2	3.6	113.9	7.4	6.5	0.6	7.2	0.2	33.3	0	44.0	6.3
2006	102.1	4.0	99.1	1.5	5.6	0.3	5.5	0.7	40.5	6.6	34.5	2.0
2007	106.5	5.4	113.8	3.4	5.2	0.2	5.5	0.2	34.8	4.3	46.9	2.8

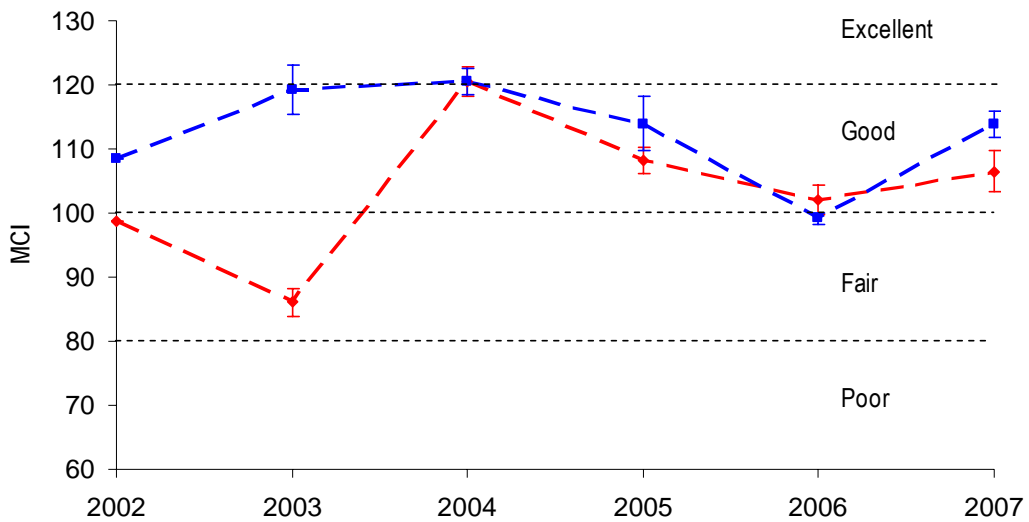


Figure 4.9: Mean MCI values (± 1 standard error) based on annual samples collected upstream (red) of and within the rehabilitation area (downstream – blue) on the Enaki Stream. No trends were apparent over time (2002 – 2007), nor for the other indices examined (SQMCI and %EPT taxa). Black dashed lines indicate thresholds from Stark and Maxted (2007).

(c) Fish

Fish communities in both reaches of the Enaki Stream were dominated by longfin eels and upland bullies which were found in reasonable numbers during all three sampling events in 2002, 2003 and 2007. Torrentfish, brown trout, shortfin eels, common bullies (one) and koura were also present over the reporting period but generally in lower numbers. Overall, there was little difference evident between fish and koura communities for the two sites (Table 4.6), though, in 2007, a more diverse fauna was caught both upstream of and within the rehabilitation area.

Table 4.6: Fish species (and koura) found upstream of and within the rehabilitation area of the Enaki Stream in 2002, 2003, and 2007. - = absent (0), + = rare (1 - 3), ++ = common (4 - 10), +++ = abundant (10+).

Fish/crustacean	Upstream			Downstream		
	2002	2003	2007	2002	2003	2007
Longfin eel (<i>Anguilla dieffenbachia</i>)	++	++	++	++	+	++
Shortfin eel (<i>Anguilla australis</i>)	-	+	+	-	++	+
Torrentfish (<i>Cheimarrichthys fosteri</i>)	+	-	++	-	-	+
Upland bully (<i>Gobiomorphus breviceps</i>)	++	++	++	+++	++	++
Common bully (<i>Gobiomorphus contidianus</i>)	-	-	+	-	-	-
Brown trout (<i>Salmo trutta</i>)	+	-	+	+	+	++
Koura (<i>Paranephrops planifrens</i>)	-	++	+	-	-	+

4.5 Discussion

Despite the obvious limitations of this study (e.g., fencing and extensive planting within, and upstream of, the “control” reach), monitoring shows that riparian rehabilitation along the banks of the lower reaches of the Enaki Stream has led to some improvements in physical habitat, water quality and ecosystem health. These improvements are discussed below along with factors that may be limiting some of the anticipated benefits of riparian rehabilitation.

4.5.1 Physical habitat

Vegetation within the rehabilitation area provided more cover at all height classes assessed and corresponded to an increase in streambed shade when compared with the upstream reach and earlier estimates made in 2003 (Warr 2004). Since 2003, vegetation cover and streambed shade have also increased at the upstream reach due to retiring and planting of the riparian margin. Streambed shade in both reaches is still well below that provided by complete canopy cover so further benefits can be expected as riparian plants mature. However, as complete canopy cover may take many decades to fully develop, it will be some years before the benefits of rehabilitation are fully realised (Parkyn et al. 2003).

Estimates of instream substrate were comparable between sites upstream of and within the rehabilitation area in 2007. However, compared with 2003 measurements, there may be a decrease in streambed silt cover upstream of the rehabilitation area. This may indicate that the riparian fencing and planting upstream are reducing silt inputs from diffuse inputs (Smith 1989). A reduction in silt cover, if occurring, may have significant benefits to the instream fauna as both numbers of taxa and total densities have been shown to be lower in rivers where a significant proportion of the streambed is covered in sand and/or silt (Quinn & Hickey 1990).

Notable narrowing and deepening of the stream channel has occurred within the rehabilitation area of the Enaki Stream and bank stability has also improved. These changes are consistent with reduced stock pressure on stream banks and increased vegetation growth as a result of fencing and planting (Parkyn et al. 2003). Increased bank stability is important as the Enaki Stream channel is highly mobile (Don Bell pers. comm.) which can make it difficult to manage (i.e., bridge etc.).

4.5.2 Water quality

Increased streambed shade has resulted in significantly lower water temperatures within the rehabilitation area. Continuous monitoring of water temperature showed a reduction of daily maximum temperatures by 2.5 °C. This decrease equated to a reduction in the proportion of time the upper thermal tolerance limit of sensitive stream invertebrates was exceeded from 37 % of the time upstream to 21 % within the rehabilitation area. Greater reductions in water temperature have been found in other studies when comparisons were made with mature canopy cover (e.g., Rutherford et al. 2004), which suggests further decreases in water temperature can be expected in this reach of the Enaki Stream as canopy cover increases.

Trend analysis showed water temperature was decreasing by around 0.8 °C per year from January 2002 to December 2006. This trend was apparent both upstream of and within the rehabilitation area but not at Greater Wellington's nearby State of Environment monitoring sites (see Appendix 4). This may indicate that the extensive fencing and planting carried out throughout the Enaki catchment (approximately 7 km) under Greater Wellington's riparian strategy is starting to have beneficial results (i.e., lower water temperatures) for the instream fauna of the Enaki Stream.

Median total phosphorus and total nitrogen concentrations were lower (0.0045 and 0.05 g/m³ respectively) within the rehabilitation area indicating that some interception of nutrients by the riparian margin is possibly occurring. In addition, both sites exhibited reductions in total phosphorus for the reporting period (0.0004 to 0.004 g/m³ per year for raw and flow-adjusted data respectively). However, overall, the lower concentrations are probably of little consequence to the stream ecosystem; nutrient concentrations remain elevated and above national guidelines (ANZECC 2000), with concentrations of dissolved and total nitrogen more than twice the guideline values.

Concentrations of *E. coli* remain elevated and above national guidelines (ANZECC 2000). While stock have been excluded from the rehabilitation area, stock have access to the upstream reaches (via unfenced sections of stream and stock crossings) and poor effluent disposal practices continue to result in significant faecal inputs.

Significant reductions in nutrient and *E. coli* concentrations are considered unlikely due to the location of the rehabilitation site at the bottom of an intensive dairying catchment. Water quality is frequently shown to be extremely poor in catchments with predominantly dairy land use (e.g., Wilcock et al. 1999; Milne & Perrie 2005; Perrie 2007a). Additionally, management

practices at some farms within the catchment will also likely further limit improvements in water quality. Stock still have access to the streambed at unfenced sections of the Enaki Stream and its tributaries as well as crossing the stream at regular intervals at several locations (i.e., to and from milking sheds). Direct stock access is well documented in scientific literature as a major cause of water quality and instream habitat degradation (e.g., Belsky et al. 1999; Davies-Colley et al. 2004).

Poor dairy farming practices in the Enaki Stream catchment are evidenced by the results of Greater Wellington's 2007/08 compliance inspections. Four advisory notices and two infringement notices were issued, all dealing with poor effluent disposal; dairy effluent was either entering a waterway in the catchment (Figure 4.11), or had a high potential to do so (Steven Orr, pers. comm. 2008⁶). In this case, elevated nutrient concentrations probably also reflect subsurface inputs from the shallow unconfined aquifer; Tidswell (2008) reported elevated nitrate-nitrogen concentrations in shallow groundwater around Carterton, attributed to intensive farming (a piggery and dairying) in the area.



Figure 4.11: Raw dairy shed effluent illegally discharging to a tributary of the Enaki Stream upstream of the rehabilitation area during October 2007.

4.5.3 Ecosystem health

A reduction in periphyton cover and biomass has occurred within the rehabilitation area and is mostly likely related to increased streambed shade from the planted riparian vegetation. Lower periphyton biomass could account

⁶ Greater Wellington Resource Advisor

for the lower concentrations of dissolved oxygen within the rehabilitation area (i.e., less periphyton, less photosynthetic activity, less oxygen produced, thus allowing oxygen depleting processes to become more apparent). Similarly, increasing vegetation cover at both sites may be responsible for the small decreasing trends in percent oxygen saturations (1.6 to 2 % per year) observed over the reporting period.

Streambed shade is still below the 60–90 % cover required to keep periphyton at consistently low levels (Rutherford et al. 1999). Exceedance of biomass guidelines indicates that excessive periphyton growth may be continuing to affect the health of the benthic aquatic communities. However, as riparian plants mature and streambed shade increases, further reduction in periphyton biomass can be expected.

There was no apparent improvement in the stream invertebrate community within the rehabilitation area over the reporting period. However, in 2003 the invertebrate community was significantly “healthier” within the rehabilitation area than upstream. It is possible that the riparian rehabilitation area provided a level of protection against the drought experienced at the time (extreme low flows, high water temperatures and high periphyton biomass). The absence of this protection upstream resulted in the lowest invertebrate metric scores recorded at this site during the reporting period. However, even if water quality and habitat quality improve further, significant improvements in the stream invertebrate community may not occur as the distance of the rehabilitation area from forested headwater catchments will likely influence the ability of more sensitive macroinvertebrates to re-colonise the area (Parkyn et al. 2003).

Despite a more diverse fish fauna being caught in 2007 than in previous years, there is little evidence for any improvements in the fish community structure within the rehabilitation area. The fish fauna present are all species commonly found in degraded to moderately degraded habitats and there is no indication of a shift towards a community that prefers forest cover as has been found in other studies (e.g., Richardson & Boubée 2003). Surveys within the Ruamahanga catchment (of which the Enaki Stream is a tributary) have shown fish diversity and abundance to be surprisingly low (Joy 2002). It is unclear what is causing this low fish diversity but Warr (2004) speculated that it is likely related to the presence of physical (e.g., a blocked Lake Onoke restricting the entry of diadromous fish) and/or chemical barriers (such as sewage discharges). These issues mean that it may be unrealistic to expect increased diversity of migratory fish species within the rehabilitation area of the Enaki Stream.

4.5.4 Synthesis

Riparian rehabilitation along a reach of the lower Enaki Stream has resulted in improvements in aesthetics (refer to Figure 4.3), bank stability, streambed shading, instream temperatures, as well as aspects of water quality and habitat quality. The rehabilitation area also appears to buffer against the detrimental effects from extreme environmental conditions; the stream invertebrate community was noticeably healthier within the rehabilitation area compared with that upstream during drought conditions in 2003.

The observed improvements reflect those anticipated prior to commencement of the study (see Section 2.1.1), with the biggest improvements expected in bank stability, streambed shade and aesthetics. However, despite these improvements, water quality remains degraded with elevated concentrations of nutrients and faecal bacteria reflecting intensive dairy farming within the catchment. Periphyton biomass as well as invertebrate and fish community composition also suggest that the Enaki Stream ecosystem remains in a degraded state. Even though the full benefits of riparian rehabilitation can take decades to become apparent, the potential for improvements along this section of the Enaki Stream will continue to be limited by the location of the rehabilitation area at the bottom of an intensive dairying catchment.

5. Kakariki Stream

5.1 Overview of the Kakariki catchment

The Kakariki Stream has a catchment area of approximately 780 hectares and is a tributary of the Ngarara Stream on the Kapiti Coast (Figure 5.1). The Ngarara Stream and its tributaries are identified in Greater Wellington's Regional Freshwater Plan (1999) as in need of enhancement for aquatic ecosystem purposes.

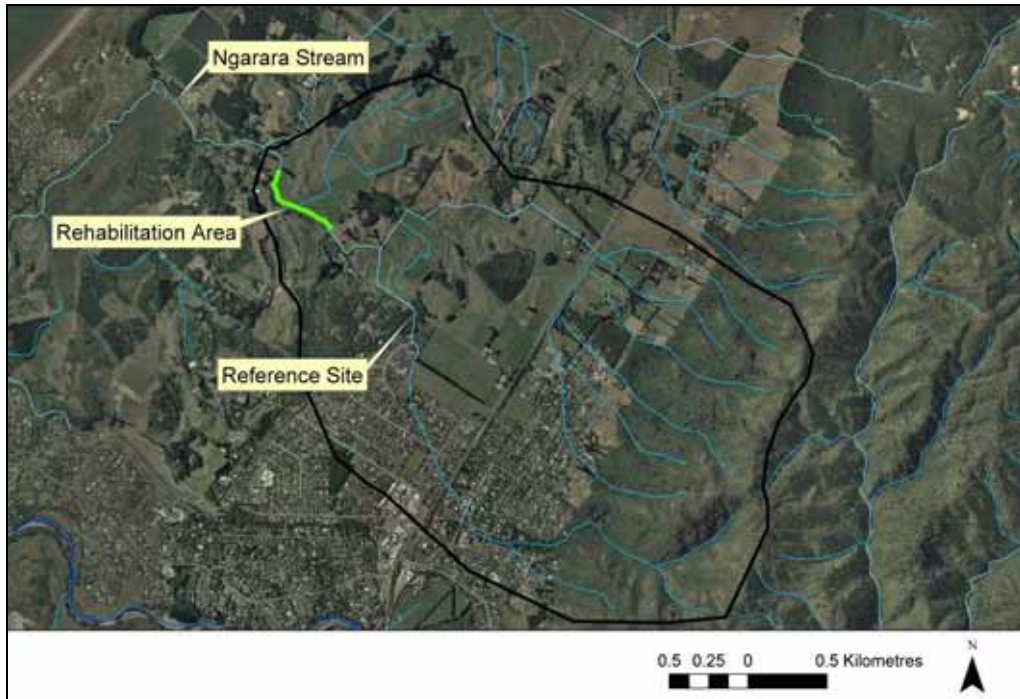


Figure 5.1: Kakariki Stream catchment showing the stretch of stream undergoing riparian rehabilitation and the reference site on a tributary.

The Kakariki Stream originates in the foothills of the Tararua Range where geology is predominantly greywacke. The stream then flows through a largely low-lying catchment comprising alluvial gravels, windblown sands and peat. Though the upper catchment remains in indigenous forest almost half of the catchment has been developed as pastoral farmland including sheep, beef and dairy. The stream is also affected by urban runoff as a section of the stream runs through Waikanae township (approximately 20 % of the catchment is under urban land use).

The rehabilitation area is located close to the bottom of the catchment downstream of Nga Manu Bird Sanctuary and is surrounded in the immediate area by sheep and beef farmland. Approximately 800 m of the Kakariki Stream has been set aside for riparian rehabilitation. Fencing and planting occurred during 2000 and 2001.

5.2 Monitoring sites

Monitoring was carried out at the sites shown in Figure 5.2. Approximately 500 m of stream length separates the two monitoring sites and this represents the upstream and downstream boundaries of the area originally fenced and planted. The site upstream of the rehabilitation area was selected to provide results that represent pre-rehabilitation conditions (i.e., a control site); these results could then be compared with those collected from the downstream site (within the rehabilitation area) to determine the effects riparian rehabilitation is having on physical habitat, water quality and stream health.

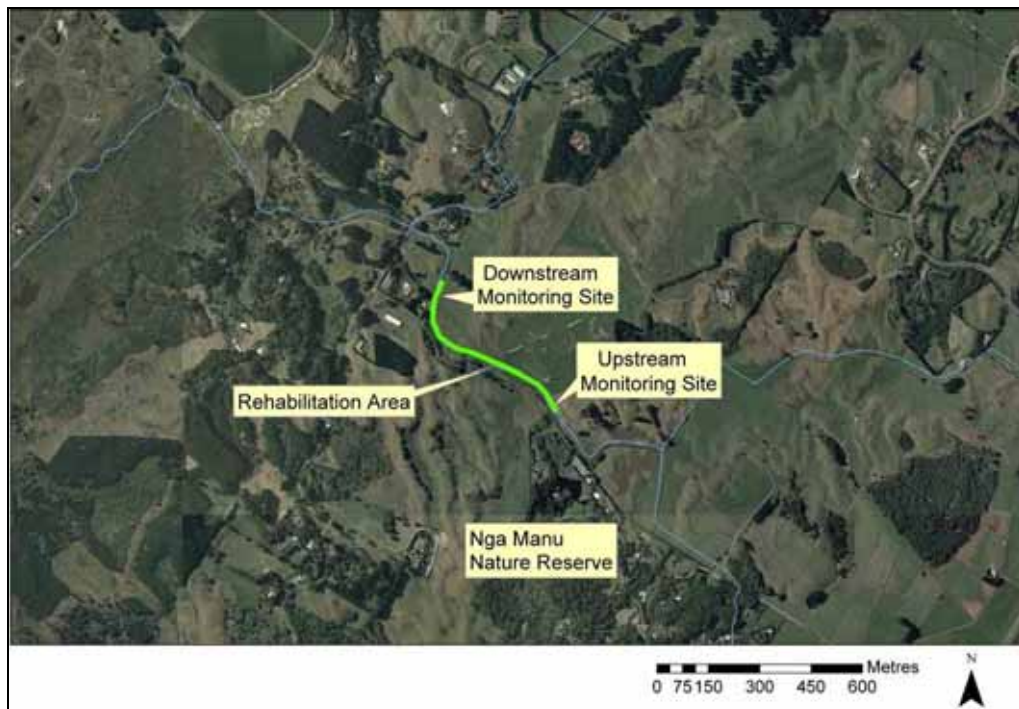


Figure 5.2: Kakariki Stream and the monitoring sites upstream of and within the rehabilitation area (downstream site).

A site with an intact riparian margin was also monitored with the aim of providing a benchmark against which changes within the rehabilitation area could be compared. The reference site is a tributary located approximately 500 m upstream of the rehabilitation area within a small forested area on the boundary of the Waikanae township (refer Figure 5.1). This site was selected to represent conditions in the rehabilitation area once riparian planting has matured. However, water quality and biological monitoring has shown that the overriding influence of urban runoff on water quality in this reach limits its usefulness as a benchmark for the rehabilitation area. For this reason, the monitoring results for this reference site are not discussed in any detail in this report.

5.3 Study limitations

Soon after monitoring began, a 200 m reach of stream immediately above the upstream monitoring site was fenced off and planted. This means that the upstream monitoring site is no longer truly representative of pre-rehabilitation

(or control) conditions and will limit the value of comparisons between monitoring sites. In 2007, the habitat assessment was carried out upstream of this area so these results will not be affected. However, water quality and biological monitoring results from the upstream site may be influenced by this additional fencing and planting that occurred upstream.

5.4 Results

This section presents the results of a physical habitat assessment, physico-chemical and microbiological water quality monitoring, and biological assessments for sites upstream of and within the riparian rehabilitation area on the Kakariki Stream. Where appropriate, comparisons with habitat assessments carried out in 2003 (Warr 2004) are presented.

Where applicable, habitat assessment and monitoring results are also presented for the nearby reference site. Full water quality and biological results for the reference site are presented in Appendix 6. Warr (2004) previously reported that channel morphology, instream habitat characteristics, water quality and the biological communities of the reference stream differed significantly from that found within the riparian rehabilitation study area. For this reason the reference site is mostly used to compare vegetation cover characteristics with the rehabilitation area and to help verify that any trends observed within the rehabilitation area are more likely to be associated with the fencing and planting rather than broader scale catchment effects.

5.4.1 Physical habitat assessment

(a) Vegetation and shade

Vegetation cover within the rehabilitation area of the Kakariki Stream was greater than that upstream (Figure 5.3). This was most obvious in the 0.5 m to 5 m height class; there was 34 % cover within the rehabilitation area compared with just 8 % cover upstream (Figure 5.4).

Vegetation cover between 0.5–5 m was dominated by planted natives including flaxes, caprosmas, manuka, mahoe and cabbage trees. The density of plantings was on average four plants per transect; there were no plantings in the upstream reach. Vegetation greater than 5 m was minimal (non-existent upstream), with the rehabilitation site averaging just 1 % cover in this height class. In comparison, vegetation cover in this height class at the reference site (which has mature canopy cover) was 91 %. Overall, estimates for vegetation cover for all height classes were not too dissimilar to values previously estimated in 2003.

Estimates of streambed shade within the rehabilitation area were double that of the upstream reach; 19 % and 9 % respectively. However, this is still well below the 84 % streambed shade estimated at the reference site (Figure 5.5). As with vegetation cover, estimates of shade were similar to those previously reported in 2003.



Figure 5.3: Typical stream reaches at the upstream site (top) and within the rehabilitation area (downstream site). Photos taken in 2008.

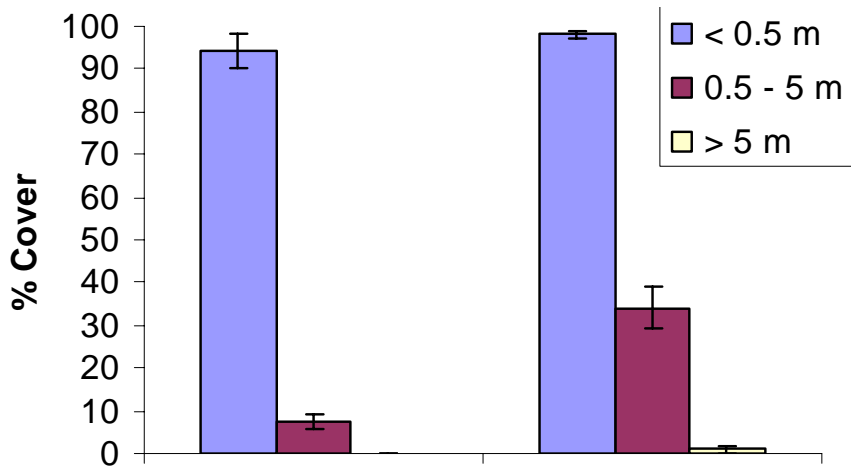


Figure 5.4: Percentage cover (± 1 standard error) of vegetation < 0.5 m, 0.5 – 5 m and > 5 m tall on riparian margins upstream of and within the rehabilitation area (downstream) on the Kakariki Stream.



Figure 5.5: Mature canopy cover at the reference site, which provided four times greater streambed shade cover than vegetation at the rehabilitation site.

(b) Channel characteristics

Average bank height and water level width were less upstream of the rehabilitation area, but overall, measures of channel morphology were fairly similar between reaches (Table 5.1). Channel morphology at the reference site was quite different with bank height less than half that found within the rehabilitation area and the average maximum depth just 0.15 m.

Table 5.1: Average channel dimensions (m) upstream of and within the rehabilitation area (downstream) of the Kakariki Stream.

Site	Water level width	Mid bank width	Bank full width	Bank height	Max depth
Upstream	1.70	2.36	3.07	0.86	0.54
Downstream	1.99	2.31	3.06	1.10	0.61

Bank stability scores improved from poor to fair between the unfenced upstream site and the rehabilitation area, the same as found in 2003. Undercutting and slumping of banks, while still present within the rehabilitation area, were more common upstream (Figure 5.6).



Figure 5.6: Upstream of the rehabilitation area erosion and slumping were common resulting in lower bank stability. Photo taken in 2008.

(c) Instream characteristics

Substrate both within and upstream of the rehabilitation comprised 100 % silt (Figure 5.7). Substrate cover at the nearby reference site was very different and comprised moderate amounts of large and small cobbles as well as large and small gravels.



Figure 5.7: Silt substrate along the true right bank within the rehabilitation area. Note the tannin-stained water.

Average macrophyte cover (emergent) was similar upstream of and within the rehabilitation site; 12 % and 8 % respectively (Table 5.2). In both cases cover was considerably less than the values reported in 2003 (54 % and 40 % respectively). Monthly estimates of macrophyte cover were not carried out as part of this study but anecdotal evidence indicates that coverage within the rehabilitation area has been declining throughout the reporting period⁷.

Overhanging vegetation was greater within the rehabilitation area than upstream and the 2007 measurements are at similar levels to those reported in 2003. Cover of woody debris could not be assessed in 2007 as the water was too turbid (silts and tannins).

⁷ Macrophyte cover within the rehabilitation area was close to 100 % when grazing pressure was reduced through fencing off of the riparian margin at the commencement of this study (Warr 2004).

Table 5.2: Instream characteristics upstream of and within the rehabilitation area (downstream) on the Kakariki Stream.

Site	Overhanging vegetation (m)	Woody debris cover (%)	Macrophyte cover (%)
Upstream	0.11	Not assessed	12
Downstream	0.37	Not assessed	8

5.4.2 Water quality

Monthly water quality monitoring for the reporting period is summarised in Table 5.3. At both sites median concentrations of both total and dissolved nutrients and *E. coli* are all well above national (ANZECC 2000) water quality guideline values for lowland streams (see Appendix 2). Over the reporting period, dissolved oxygen concentrations below the recommended threshold (5 g/m^3) for the protection of fish communities (Dean & Richardson 1999) were recorded at both sites.

Table 5.3: Summary of physico-chemical and microbiological water quality data, based on monthly monitoring over January 2002 to December 2006 for the Kakariki Stream, upstream of and within the rehabilitation area (downstream). Statistically significant differences ($p < 0.05$) between median values are shown in bold font.

Variable	Upstream				Downstream			
	Med	Min	Max	<i>n</i>	Med	Min	Max	<i>n</i>
Temperature (°C)	14.7	9.4	21.6	56	14.9	9.3	20.7	56
Dissolved Oxygen (% saturation)	78.1	42.1	112	53	74	25.2	141	53
Dissolved Oxygen (g/m^3)	7.75	3.8	11.2	53	7.67	2.38	10.5	53
pH	6.83	5.19	10.6	51	6.86	5.23	9.29	51
Turbidity (NTU)	8.77	2.25	84.4	58	11.2	2.42	86.6	58
Total Suspended Solids (g/m^3)	9	1.5	117	58	8.5	1.5	102	58
Conductivity ($\mu\text{S/cm}$)	254	153	471	55	272	168	497	55
Total Organic Carbon (g/m^3)	11.7	6.1	25.4	58	11.4	2.1	23.9	58
Nitrite-Nitrate Nitrogen	0.662	0.003	4.15	57	0.645	0.001	3.78	58
Ammoniacal Nitrogen (g/m^3)	0.11	0.01	0.26	58	0.12	0.005	0.27	58
Total Kjeldahl Nitrogen (g/m^3)	0.8	0.3	2	58	0.8	0.3	2	58
Total Nitrogen (g/m^3)	1.5	0.3	5.6	58	1.4	0.3	5.2	58
Dissolved Reactive Phosphorus (g/m^3)	0.024	0.008	0.300	58	0.025	0.008	0.062	58
Total Phosphorus (g/m^3)	0.088	0.036	0.360	58	0.098	0.054	0.372	58
<i>E. coli</i> (cfu/100mL)	700	25	28,000	58	755	50	23,200	58

Analysis of median water quality results (see Appendix 3 for full details) from monitoring sites located upstream of and within the rehabilitation area highlighted a number of significant differences ($p < 0.05$). Compared with the upstream site the rehabilitation area had:

- significantly lower concentrations of nitrite-nitrate nitrogen, total nitrogen, total organic carbon and dissolved oxygen (including percent saturation), as well as lower water temperatures (although this was only evident in continuous monitoring data); and

- significantly higher concentrations of dissolved reactive phosphorus and total phosphorus as well as higher pH, turbidity and conductivity levels.

Although there was no difference between monthly spot water temperature measurements recorded within the rehabilitation area and upstream during the reporting period, continuous water temperatures during March 2007 were significantly ($p < 0.05$) lower within the rehabilitation area (Figure 5.8). Mean daily temperatures for this period were 1.4 °C lower than upstream and the maximum daily temperatures were on average 2 °C lower. Minimum daily temperatures for this time period were also lower (1.0 °C) within the rehabilitation area.

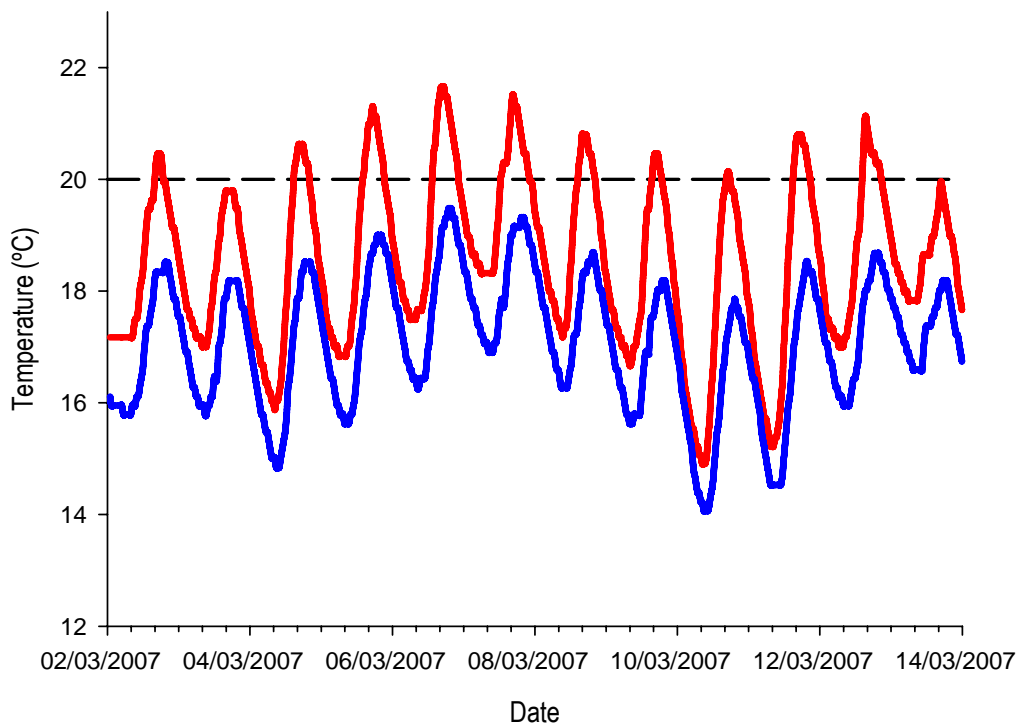


Figure 5.8: Water temperature at sites upstream (red) of and within the rehabilitation area (downstream – blue) on the Kakariki Stream, based on continuous monitoring between 2 March 2007 and 14 March 2007. The dashed line represents the upper thermal tolerance for sensitive invertebrate species (Rutherford et al. 1999).

Conductivity values were consistently higher within the rehabilitation area (approximately 20 $\mu\text{s}/\text{cm}$ higher, Figure 5.9) and may indicate an input of groundwater between the upstream and downstream monitoring sites. This is discussed further in Section 5.5.

Median concentrations of both total and dissolved nitrogen were lower within the rehabilitation area (0.1 g/m^3 and 0.017 g/m^3 lower respectively). Conversely, median concentrations of both total and dissolved phosphorus were higher within the rehabilitation area (0.0105 g/m^3 and 0.0015 g/m^3 higher respectively).

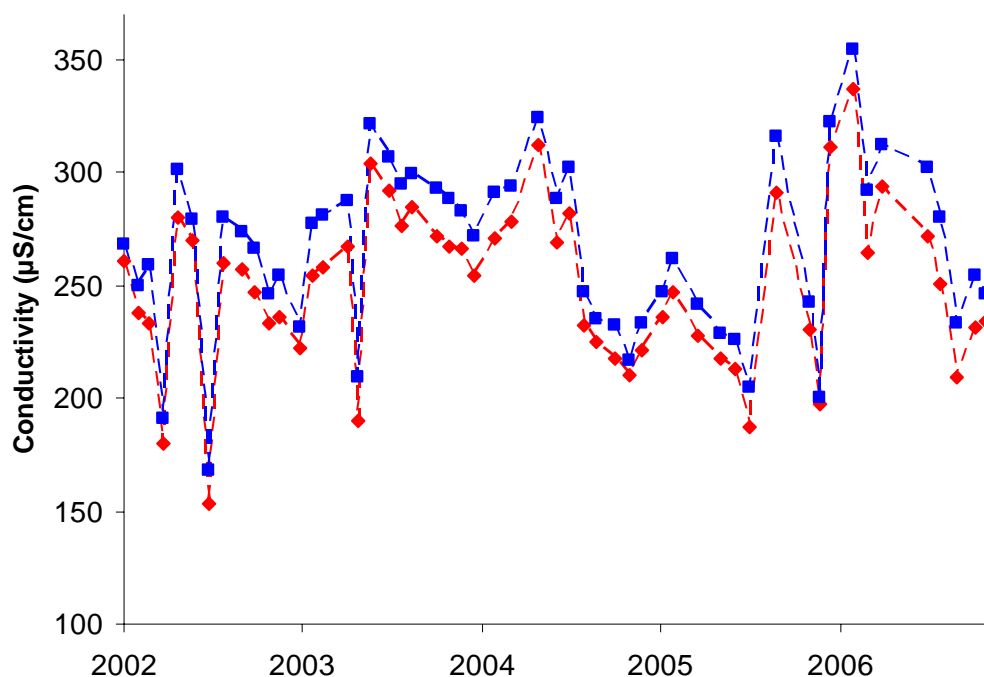


Figure 5.9: Conductivity measurements based on monthly monitoring from sites upstream (red) of and within the rehabilitation area (downstream – blue) on the Kakariki Stream for the period January 2002 to December 2006.

Significant trends ($p < 0.05$) detected by Seasonal Kendall trend analyses are summarised in Table 5.4; full details are provided in Appendix 4. Dissolved oxygen increased within the rehabilitation area during the reporting period by 3 % and 0.35 g/m^3 per year in the raw data (Figure 5.10) and slightly less using flow-adjusted data. Other significant trends observed within the rehabilitation area were decreasing concentrations of total phosphorus (0.007 g/m^3 per year) and increasing concentrations of dissolved reactive phosphorus (0.004 g/m^3 per year); the latter trend was also apparent in data collected from the upstream monitoring site.

Table 5.4: Trend slopes (units per year) for raw and flow-adjusted water quality variables that exhibited significant trends ($p < 0.05$) at sites upstream of and within the rehabilitation area (downstream) on the Kakariki Stream. NS denotes non-significant (i.e., no trend).

Variable	Upstream		Downstream	
	Raw	Flow-adjusted	Raw	Flow-adjusted
Turbidity (NTU)	0.77	0.65	NS	NS
Total Suspended Solids (g/m^3)	1.194	1.279	NS	NS
Dissolved Oxygen (% saturation)	NS	NS	3.00	2.38
Dissolved Oxygen (g/m^3)	NS	NS	0.35	0.23
Total Organic Carbon (g/m^3)	NS	0.64	NS	NS
Total Phosphorus (g/m^3)	NS	NS	NS	-0.0070
Dissolved Reactive Phosphorus (g/m^3)	0.0040	0.0038	0.0041	0.0043

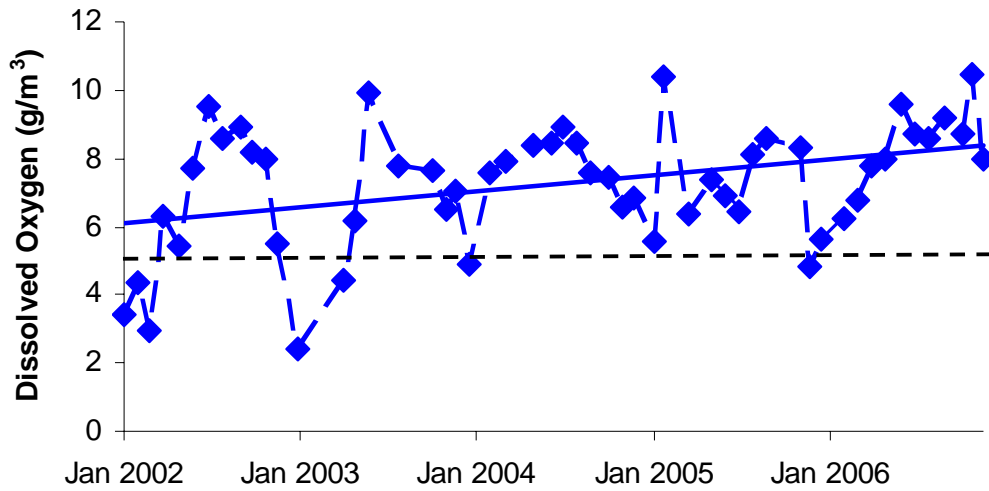


Figure 5.10: Monthly dissolved oxygen concentrations recorded within the rehabilitation area (downstream) over January 2002 to December 2006. The solid blue line represents the overall trend for the data record (raw data). The dashed line represents the 5 g/m³ threshold recommended for the protection of fish communities (Dean & Richardson 1999).

Upstream of the rehabilitation area, increases in turbidity, total suspended solids and total organic carbon occurred over the duration of the reporting period. These trends were not observed within the rehabilitation area.

Trends that occurred upstream of or within the rehabilitation area were not apparent in data collected from the nearby reference site.

5.4.3 Biological monitoring

(a) Invertebrates

Compared with thresholds recommended by Stark and Maxted (2007), invertebrate community health, both upstream of and within the rehabilitation area, can generally be classed as ‘fair’. Invertebrate metric scores tended to be higher within the rehabilitation area than upstream for the duration of the reporting period. Invertebrate data are summarised in Table 5.10.

Table 5.10: Measures of invertebrate health (MCI, SQMCI, and % EPT taxa) for the Kakariki Stream upstream of and within the rehabilitation area (downstream), based on annual monitoring over 2002 to 2007. The 2002 scores are based on just one sample, with the mean score and standard deviation (SD) for all other years based on three replicate samples.

Year	MCI				SQMCI				% EPT (taxa)			
	Upstream		Downstream		Upstream		Downstream		Upstream		Downstream	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
2002	67.3	-	88.9	-	4.2	-	5.0	-	0	-	0	-
2003	68.8	7.7	82.5	6.5	4.3	0.2	4.1	0.1	0	0	0	0
2004	74.0	3.5	83.6	3.8	4.4	0.3	4.3	0.3	0	0	4.2	7.2
2005	71.8	3.0	93.1	14.6	4.5	0.3	4.8	0	10.0	1.5	17.0	20.6
2006	74.5	11.7	82.5	5.5	4.5	0.2	4.7	0	5.8	5.6	7.9	0.4
2007	82.5	5.6	83.2	6.2	4.6	0.1	4.5	0.2	16.4	5.2	23.7	7.8

Trend analysis showed that the proportion of pollution intolerant taxa (% EPT taxa) increased over the reporting period, both upstream of and within the rehabilitation area (Figure 5.11). No EPT taxa were recorded at either site during sampling in 2003 and 2004, however, by 2007 EPT taxa represented 16 % and 24 % of the total taxa found upstream of and within the rehabilitation site respectively. This trend was not evident in invertebrate monitoring data collected from the nearby reference site (see Appendix 5 for full details of Spearman rank correlations).

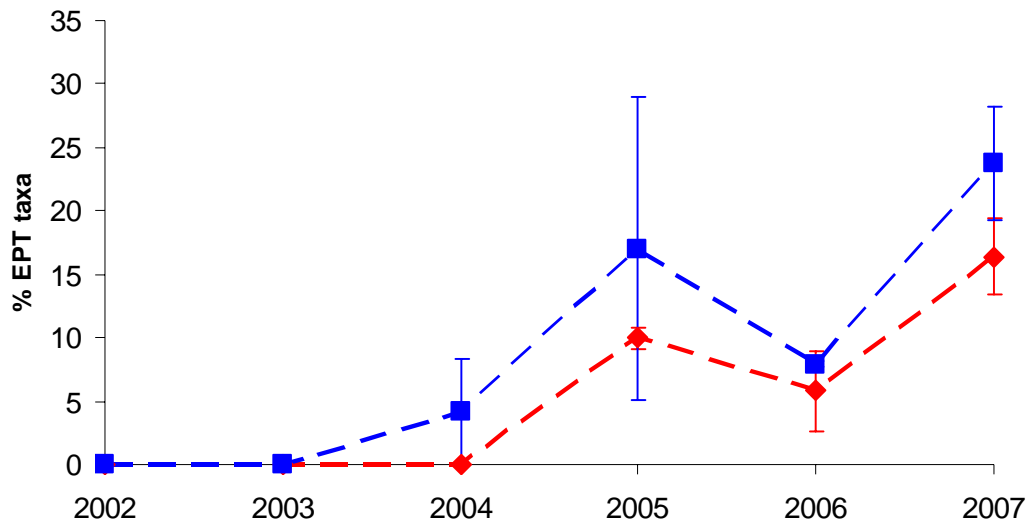


Figure 5.11: Mean percent EPT taxa values (± 1 standard error) based on annual sampling upstream (red) of and within the rehabilitation area (downstream - blue) on the Kakariki Stream over 2002 to 2007.

Small, but significant ($p < 0.05$) improvements in SQMCI and MCI values were also observed upstream of the rehabilitation area; 0.073 SQMCI and 2.6 MCI units per year respectively. These trends were not apparent within the rehabilitation area. At the reference site the only trend observed over the reporting period was a decrease in SQMCI values (0.41 SQMCI units per year).

(b) Fish

Trapping carried out in November 2007 caught large numbers of inanga and a few individuals of both common bullies and shortfin eels. Twice as many inanga were caught upstream of the rehabilitation area than within it with the catch per unit effort (CPUE i.e., the number of fish per trap) between sites significantly ($p < 0.05$) different (Figure 5.12).

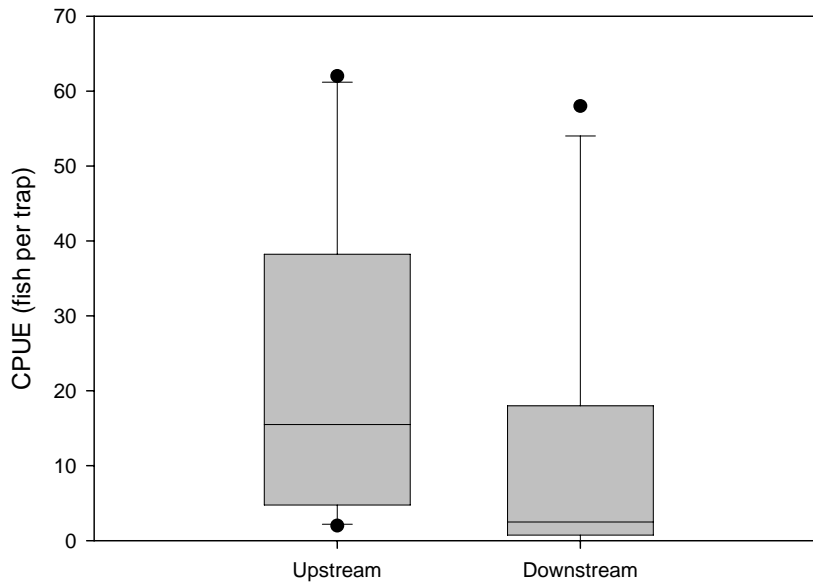


Figure 5.12: CPUE (i.e., fish per trap) for inanga caught upstream of and within the rehabilitation area (downstream) on the Kakariki Stream. Catch rates were significantly different ($p < 0.05$) between sites.

Electric fishing in the Kakariki Stream showed that the species and abundances caught varied between sampling years for both sites, with many species recorded as either common or abundant on at least one sampling occasion but absent on another (Table 5.10). Typically, shortfin eels, common bullies and inanga were recorded in reasonable abundances (common or abundant) at both sites. Longfin eels, freshwater shrimp and koura were also caught in good numbers in some years. In 2007, a previously unrecorded species (redfin bully, Figure 5.13) was caught within the rehabilitation area.

Table 5.10: Fish, koura and shrimp found upstream of and within the rehabilitation area (downstream) of the Enaki Stream in 2002, 2003, and 2007. - = absent (0), + = rare (1 - 3), ++ = common (4 - 10), +++ = abundant (10+).

Fish, koura and shrimp	Upstream			Downstream		
	2002	2003	2007	2002	2003	2007
Longfin eel (<i>Anguilla dieffenbachia</i>)	-	+	++	-	+	+
Shortfin eel (<i>Anguilla australis</i>)	++	+++	+	++	+++	-
Common bully (<i>Gobiomorphus cotidianus</i>)	+	++	+++	+	-	++
Redfin bully (<i>Gobiomorphus huttoni</i>)	-	-	-	-	-	+
Inanga (<i>Galaxias maculatus</i>)	+	++	+++	+	++	++
Shrimp (<i>Paratya curvirostris</i>)	++	-	++	++	-	+
Koura (<i>Paranephrops planifrens</i>)	-	++	++	-	++	-



Figure 5.13: In 2007, a redfin bully was caught for the first time within the rehabilitation area of the Kakariki Stream and may be an indication of improving water quality and habitat quality.

5.5 Discussion

Monitoring of physical habitat, water quality and stream health upstream of and within the rehabilitation area of the Kakariki Stream indicate a number of differences between sites, some of which represent improvements. However, measuring the extent of these benefits and relating these to the riparian rehabilitation was limited by the additional fencing and planting that occurred upstream of the rehabilitation area and by a groundwater input that occurs between the monitoring sites located upstream of and within the rehabilitation area.

5.5.1 Physical habitat

Estimates of vegetation cover within the rehabilitation area in 2007 were similar to those made in 2003, suggesting that vegetation cover has not increased significantly over the reporting period. However, this may reflect a lack of sensitivity in the visual assessment method used to estimate vegetation cover. . In 2007, vegetation cover and streambed shade were greater within the rehabilitation area than upstream.. However, current streambed shade within the rehabilitation is less than a quarter of that provided by the complete canopy cover at the nearby reference site. Therefore, further benefits from streambed shade are expected as riparian plants mature and full canopy cover is achieved.

Macrophyte cover appears to have reduced within the rehabilitation area over the course of this study and is most likely due to the increase in shade provided by riparian plants. While not formally monitored as part of this programme, anecdotal evidence indicates that macrophyte cover is decreasing. This is considered positive because although macrophytes are an important component of instream habitat, the removal of stock and subsequent reduction in grazing pressure in 2001 resulted in a proliferation of macrophytes that were implicated in the degradation of both water quality and habitat quality within the rehabilitation area (Warr 2004).

The increase in overhanging vegetation within the rehabilitation area, especially where it is submerged, has resulted in significant improvements in instream habitat quality. Habitat diversity is often low in soft bottomed streams (Stark et al. 2001) and (submerged) overhanging vegetation now appears to be playing a significant role in increasing habitat heterogeneity in the Kakariki Stream.

Exclusion of stock from the rehabilitation area has greatly improved bank stability. While some undercutting and slumping of banks remains, it is less common than upstream. Improved bank stability should help to reduce the input of sediments into the stream which can reduce habitat quality. Channel width was also greater within the rehabilitation area – while this is predicted with riparian rehabilitation (Davies-Colley 1997), there is no indication of a decline in ground vegetation cover that leads to this widening (less vegetation cover leads to increased bank erosion thus a wider channel) so it is unlikely to be related to the rehabilitating riparian zone.

5.5.2 Water quality

Monthly water quality monitoring has indicated that groundwater is entering the Kakariki Stream between the monitoring sites located upstream of and within the rehabilitation area. This was evident as conductivity measurements were consistently elevated at the monitoring site within the rehabilitation area when compared to measurements made upstream. The effect of this groundwater input on water quality monitoring results is not easily quantified. There is potential that some or all of the differences in water quality variables observed between monitoring sites could be due to this groundwater input. Additionally, this groundwater input could also be masking some of the anticipated benefits of riparian rehabilitation. Therefore, this study cannot conclusively link the changes in water quality observed within the rehabilitation area with the rehabilitating riparian zone.

The increased streambed shade provided by riparian plants within the rehabilitation area has significantly reduced mean and maximum daily water temperatures. For the summer time period examined, water temperatures within the rehabilitation area did not exceed the upper thermal tolerance for sensitive invertebrate species (20 °C), but this threshold was exceeded almost every day upstream. Temperature reduction was not as great as that reported in some other studies (e.g., Rutherford et al. 2004) but typically other studies have compared pastoral stream reaches with those under mature canopy cover. It should be noted that groundwater, typically cooler than surface water, could also be responsible for some of the reduction in water temperatures observed within the rehabilitation area.

Warr (2004) suggested that the lower dissolved oxygen concentrations recorded within the rehabilitation area on the Kakariki Stream were caused by decomposition of the large macrophyte biomass. It is possible that excessive macrophyte growth may also restrict stream flow, thereby reducing the potential for physical mixing of atmospheric oxygen (i.e., less surface turbulence). Within the rehabilitation area, dissolved oxygen concentrations were almost four times more likely to fall below thresholds recommended for

the protection of New Zealand native fish (5 g/m^3 – Dean & Richardson 1999⁸) than the upstream site. However, concentrations of dissolved oxygen did improve over the reporting period and in the latter half of this period only fell below this threshold once, compared with six times during the first half. Increasing dissolved oxygen concentrations within the rehabilitation area indicate a significant improvement in water quality in relation to ecosystem health.

There were a number of statistically significant differences in other water quality variables between the two monitoring sites; some may represent improvements in water quality within the rehabilitation area (e.g., lower concentrations of total and dissolved nitrogen) and some may represent a deterioration in water quality (e.g., higher concentrations of dissolved and total phosphorus). It is difficult to tease out the exact cause(s) for the observed differences in these water quality variables, especially considering the confounding effects of a groundwater input between monitoring sites and the fencing and planting of the upstream (control) reach. In any case, many of the differences are of such a small magnitude that they are likely to be of little consequence in terms of overall stream health.

There is no evidence that concentrations of faecal bacteria (*E. coli*) are lower within the rehabilitation area and concentrations remain well above national guidelines (ANZECC 2000). This, along with the other trends of declining water quality (increases in turbidity and concentrations of suspended solids and dissolved reactive phosphorus) recorded at the upstream site indicate that pollutants are entering the stream upstream of the rehabilitation area. Agricultural impacts (e.g., direct stock access) and urban land use impacts (notably stormwater inputs) in the upstream catchment are the likely sources of these pollutants. Degradation of water quality and habitat quality caused by land use upstream of the rehabilitation area will continue to limit the potential benefits of riparian rehabilitation along this reach of the Kakariki Stream.

5.5.3 Ecosystem health

Measures of invertebrate community health increased over the reporting period. In 2002 and 2003 no pollution sensitive species (EPT taxa) were found within any of the samples collected, but since 2004, the proportion of EPT taxa present began to increase, and in 2007 represented 24 % of the total taxa found within the rehabilitation area. The proportion of EPT taxa is typically correlated with water quality and habitat quality; the greater proportion of EPT taxa the better the water quality (e.g., Milne & Perrie 2005). A similar, but smaller, improvement was observed at the monitoring site upstream of the rehabilitation area and is probably related to the improved habitat quality that has occurred in this reach through additional fencing and planting.

Within the rehabilitation area there is also some indication that changes in the fish community structure may be occurring. In the Waikato region, Richardson & Boubee (2003) found that riparian rehabilitation led to an increase in the

⁸ Recommended critical dissolved oxygen concentration thresholds change depending on the fish community requiring protection.

abundance of species that prefer forested streams and a decrease in those that are tolerant of the degraded conditions typically found in pastoral streams. Trapping results from this study indicate that the community structure of the rehabilitation area may be in the early stages of such a change. In this case, significantly less inanga were caught within the rehabilitation area; inanga do not have the same strong correlation with forest cover that other galaxiid species have (McDowall 1990) and have also been shown to prefer water temperatures more similar to those upstream of the rehabilitation area (Richardson et al. 1994). The decrease in inanga within the rehabilitation area should not be viewed as a deterioration in fish habitat quality but as habitat improving for less tolerant species (e.g., giant kokopu). For the first time in 2007, a redfin bully was recorded within the rehabilitation area. This species is not considered overly tolerant of poor habitat quality (McDowall 1990) and the presence of this species could be a further indication that riparian rehabilitation is improving the instream habitat quality of the Kakariki Stream.

5.5.4 Synthesis

Despite the limitations of this study, riparian rehabilitation along a section of the Kakariki Stream appears to have resulted in improvements in aesthetics (refer Figure 5.3) and bank stability as well as aspects of habitat and water quality. Subsequently, measures of stream health also appear to be improving, with increases in the number of sensitive invertebrate taxa found over the reporting period and some encouraging evidence that the fish community may be beginning to shift away from a community dominated by species tolerant of degradation. These improvements typically reflect those expected to occur prior to the commencement of riparian rehabilitation (see Section 2.1.2) although some anticipated benefits will not become apparent until riparian plants mature and others may not occur due to pollutants (e.g., nutrients and faecal bacteria) entering upstream of the rehabilitation area. Elevated concentrations of nutrients and faecal bacteria, low overall invertebrate metric scores and a fish community dominated by tolerant species all indicate that despite riparian rehabilitation the Kakariki Stream remains in a degraded state and some of the benefits anticipated through riparian rehabilitation will continue to be limited by agricultural and urban land use impacts in the upstream catchment.

6. Karori

6.1 Overview of Karori catchment

The Karori Stream originates in the hills around South Karori in Wellington City. Its catchment covers an area of 3,094 hectares and is dominated by steep hilly terrain (Figure 6.1). The catchment is primarily of greywacke geology. Urban land use dominates the headwaters of this stream and the channel is highly modified in many areas.

Long term monitoring under Greater Wellington's Rivers State of the Environment monitoring programme has shown the Karori Stream to have poor water quality; the stream consistently records the highest faecal bacteria (*E. coli*) concentrations in the region (e.g., Perrie 2007b) and also has elevated nitrate nitrogen concentrations. Invertebrate monitoring indicates that the stream is severely degraded. Stormwater runoff and sewer cross connections are thought to be primarily responsible for the poor health of the Karori Stream (Warr 2004).

The rehabilitation area is located at the Makara Peak Mountain Bike Park. Approximately 1.3 kilometres of stream reach has been set aside for riparian planting. The catchment area upstream of this point is 682 hectares, over 50 % of which is in urban land use. Planting in the rehabilitation area began in 2001.

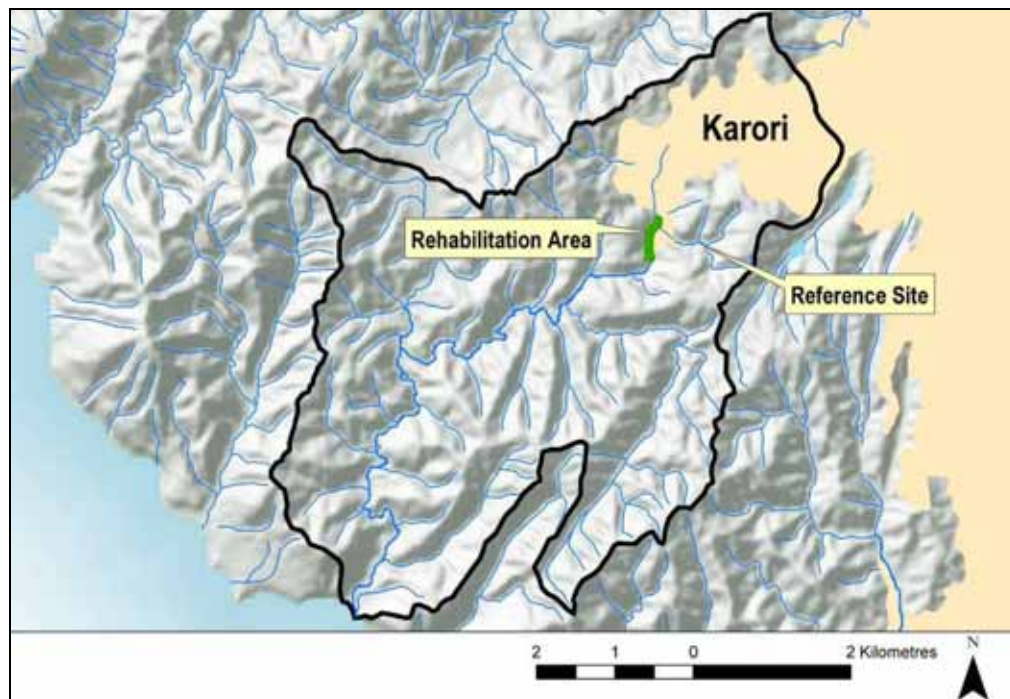


Figure 6.1: Karori Stream catchment showing the stretch of stream along which riparian rehabilitation is taking place and the location of the reference site.

6.2 Monitoring sites

Monitoring was carried out at the sites shown in Figure 6.2. Approximately 500 m of stream length separates the two monitoring sites and this represents the upstream and downstream boundaries of the area originally planted. The

site upstream of the rehabilitation area was monitored to provide results that represent pre-rehabilitation conditions (i.e., a control site); these results could then be compared with those collected from the downstream site (within the rehabilitation area) to determine the effects riparian rehabilitation is having on physical habitat, water quality and stream health. Planting has since occurred downstream of this area.

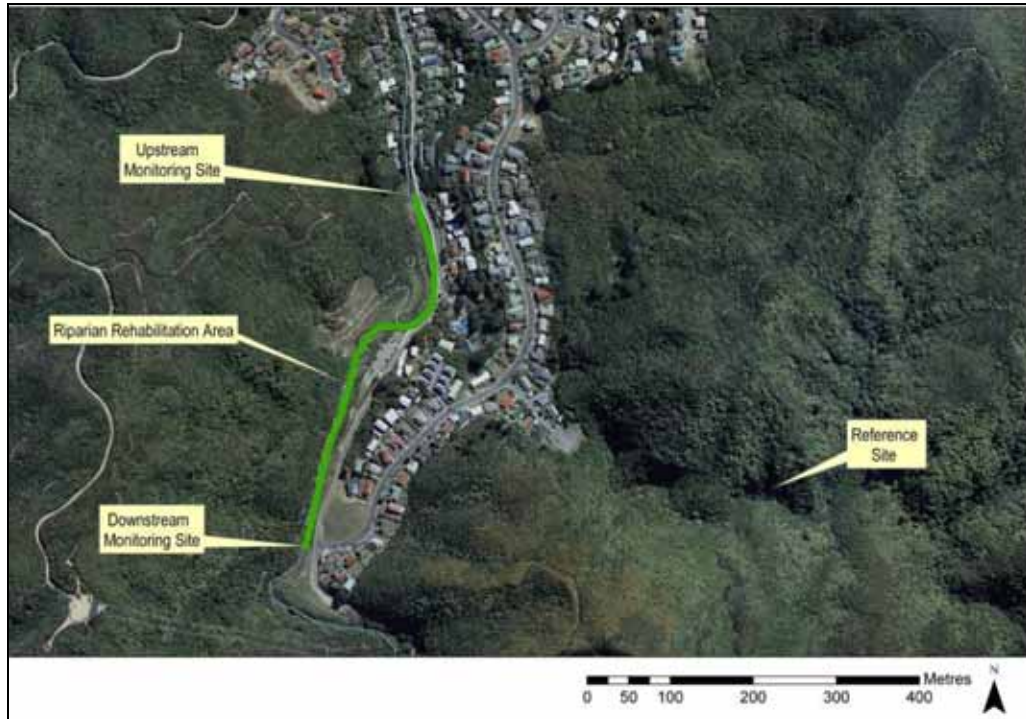


Figure 6.2: Karori Stream and monitoring sites upstream of and within the rehabilitation area (downstream site) and the reference site on a tributary.

A site with an intact riparian margin was also monitored with the aim of providing reference information against which changes within the rehabilitation area could be compared. The reference site is a tributary with a forested catchment located at Wrights Hill Reserve.

6.3 Study limitations

A tributary (containing the reference site) enters the Karori Stream between the upstream and downstream monitoring sites. While this tributary was monitored upstream of the confluence (i.e., reference site), this input is a confounding factor in measuring improvements in water quality and stream health that may occur over time with the rehabilitation of the riparian zone.

6.4 Results

This section presents the results of a physical habitat assessment, physico-chemical and microbiological water quality monitoring, and biological assessments for sites upstream of and within the riparian rehabilitation area on the Karori Stream. Where appropriate, comparisons with habitat assessments carried out in 2003 (Warr 2004) are presented.

Where applicable, habitat assessment and monitoring results are also presented for the nearby reference site. Full water quality and biological results for this reference site are presented in Appendix 6. Warr (2004) previously reported that channel morphology, instream habitat characteristics, water quality and the biological communities of the reference stream differed significantly from that found within the riparian rehabilitation study area. For this reason the reference site is mostly used to compare vegetation cover characteristics with the rehabilitation area and to help verify that any trends observed within the rehabilitation area are more likely to be associated with the fencing and planting rather than broader scale catchment effects.

6.4.1 Physical habitat assessment

(a) Vegetation and shade

Vegetation cover was greater upstream of the rehabilitation area on the Karori Stream (Figure 6.3); the upstream reach runs alongside residential properties and South Karori Road. Trees and shrubs planted in people’s back yards and along the road provided more vegetation cover; this was most noticeable in the height class greater than 5 m (Figure 6.4). Vegetation cover at the upstream site consists of a mixture of native and exotic trees and shrubs, including lemonwood, ponga, silver birch, willow and wild cherry.



Figure 6.3: Monitoring sites upstream (left) of and within the rehabilitation area (downstream) on the Karori Stream. Photos taken in 2003 and 2006 respectively.

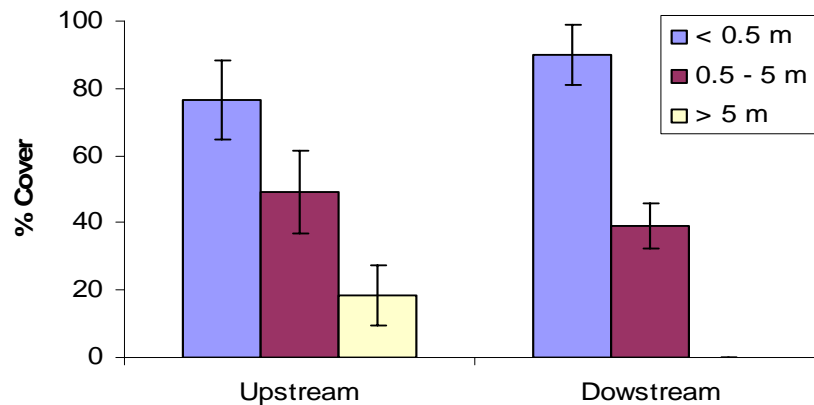


Figure 6.4: Percentage cover (± 1 standard error) of vegetation < 0.5 m, 0.5 – 5 m and > 5 m tall on riparian margins upstream of and within the rehabilitation area (downstream) on the Karori Stream.

Estimates of vegetation cover at both sites were fairly similar to those made in 2003. There were on average six plantings per transect within the rehabilitation reach. These plantings consisted of a variety of natives including flax, lemonwood, kowhai, ponga, and manuka.

Increased vegetation cover upstream corresponded to increased streambed shade with estimates of 58 % upstream compared to just 23 % within the rehabilitation area. In comparison, streambed shade was estimated at 76 % for the nearby reference site which has complete canopy cover (Figure 6.5).



Figure 6.5: The mature canopy cover at the reference site provided significantly more streambed shade than vegetation cover within the rehabilitation area. Photo taken in 2003.

(b) Channel characteristics

The upstream reach of the rehabilitation area on the Karori Stream is heavily channelised while the rehabilitation reach still retains a natural meandering form. Despite this, channel width, full bank width, bank height and maximum depth were fairly similar for the upstream and the rehabilitation reaches (Table 6.1).

Table 6.1: Average channel dimensions (m) upstream of and within the rehabilitation area (downstream) on the Karori Stream.

Site	Water level width	Mid bank width	Bank full width	Bank height	Max depth
Upstream	3.63	5.23	6.73	2.13	0.17
Downstream	3.38	5.21	7.73	2.18	0.21

Pfankuch scores for bank stability were similar between both sites, indicating good stability. However, bank form was very different between sites, with both stream banks upstream highly modified (Figure 6.6).

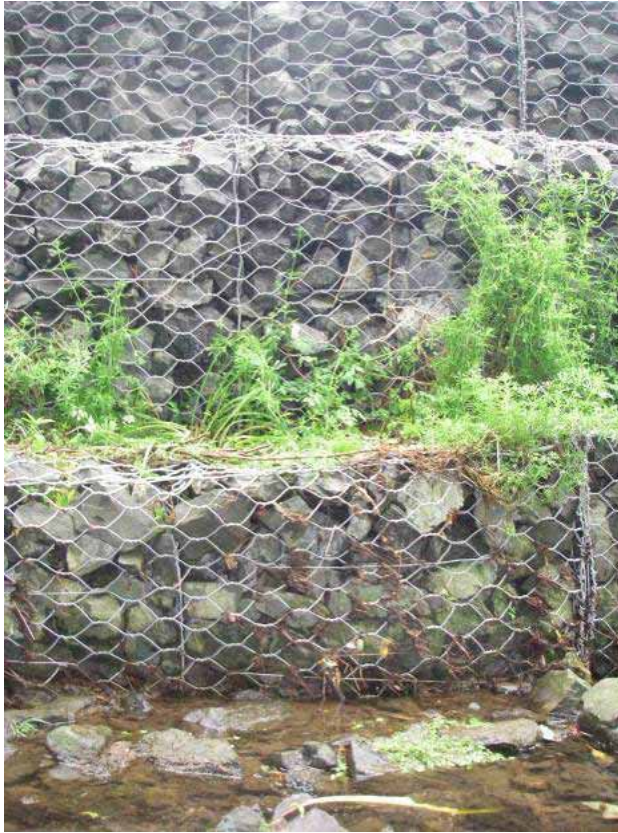


Figure 6.6: Banks along the reach upstream of the rehabilitation area are highly modified, with gabion baskets used to stabilise the banks.

(c) Instream characteristics

Substrate composition was similar at both sites on the Karori Stream (Figure 6.7) and was fairly evenly spread between large cobbles and small gravels. However, the rehabilitation area had a higher proportion of bedrock while boulders were more common in the upstream reach.

Average overhanging vegetation estimates were higher within the rehabilitation area (Table 6.2). Upstream, the highly modified banks are probably limiting vegetative growth. A small amount of woody debris and macrophyte cover was present upstream but absent within the rehabilitation area. Cover of woody debris at the reference site with mature canopy cover was 4 %. There was little or no difference in measures of instream characteristics with earlier estimates made in 2003.

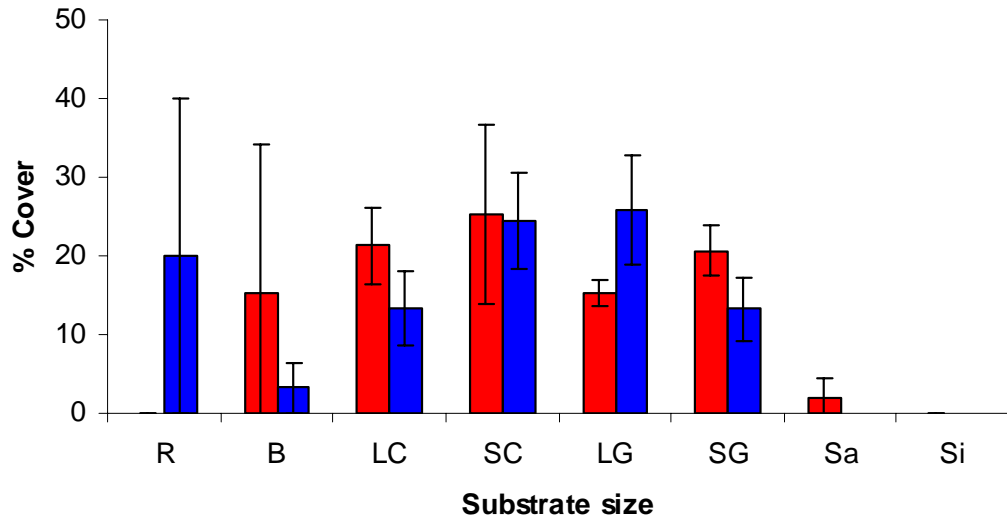


Figure 6.7: Average percent composition (± 1 standard error) of substrate size classes upstream (red) of and within the rehabilitation area (downstream – blue) on the Karori Stream. R = bedrock, B = boulders (> 256 mm), LC = large cobbles (128 - 256 mm), SC = small cobbles (64 – 128 mm), LG = large gravel (16 – 64 mm), SG = small gravel (2 - 16 mm), Sa = sand, Si = silt

Table 6.2: Instream characteristics upstream of and within the rehabilitation area (downstream) on the Karori Stream

Site	Overhanging vegetation (m)	Woody debris cover (%)	Macrophyte cover (%)
Upstream	0.26	0.83	0.83
Downstream	0.63	0	0

6.4.2 Water quality

Median concentrations of both total and dissolved nutrients and *E. coli* bacteria are all well above national (ANZECC 2000) water quality guidelines for lowland streams (see Appendix 2). Monthly water quality data collected over the reporting period is summarised in Table 6.3.

Analysis of median water quality results showed many statistically significant differences ($p < 0.05$) between monitoring sites (full details of analysis are in Appendix 3). Compared with the upstream site the rehabilitation area had:

- significantly lower turbidity and concentrations of nitrite-nitrate nitrogen, total nitrogen, dissolved reactive phosphorus, total phosphorus, and *E. coli*; and
- significantly higher water temperature, pH and dissolved oxygen (concentration and percent saturation).

Table 6.3: Summary of physico-chemical and microbiological water quality data, based on monthly monitoring over January 2002 to December 2006 for the Karori Stream, upstream of and within the rehabilitation area (downstream). Statistically significant differences ($p < 0.05$) between median values are shown in bold font.

Variable	Upstream				Downstream			
	Med	Min	Max	<i>n</i>	Med	Min	Max	<i>n</i>
Temperature (°C)	12.24	9.09	17.2	56	12.95	9.15	18.8	56
Dissolved Oxygen (% saturation)	97.5	78.4	120	54	101.4	73.2	122	53
Dissolved Oxygen (g/m ³)	10.39	8.43	13.23	54	10.85	7.95	13.69	54
pH	7.07	5.28	9.69	48	7.33	5.2	9.56	50
Turbidity (NTU)	1.23	0.64	116	57	1.13	0.54	68.7	57
Total Suspended Solids (g/m ³)	1.5	1.5	84	57	1.5	1.5	44	57
Conductivity (µS/cm)	221	125	424	55	222	131	446	55
Total Organic Carbon (g/m ³)	1.7	0.25	31.7	57	1.6	0.5	21.5	57
Nitrite-Nitrate Nitrogen	1.65	0.787	1.99	57	1.43	0.652	1.73	56
Ammoniacal Nitrogen (g/m ³)	0.02	0.005	0.13	57	0.01	0.005	0.05	57
Total Kjeldahl Nitrogen (g/m ³)	0.2	0.05	0.8	57	0.2	0.05	1.6	57
Total Nitrogen (g/m ³)	1.9	0.8	2.2	57	1.6	0.9	3.1	57
Dissolved React. Phosphorus (g/m ³)	0.037	0.012	0.07	57	0.034	0.015	0.064	57
Total Phosphorus (g/m ³)	0.053	0.025	0.3	57	0.049	0.023	3.29	57
<i>E. coli</i> (cfu/100mL)	870	172	17,280	57	560	36	19,220	57

The differences in water quality between monitoring sites upstream of and within the rehabilitation area are most evident in *E. coli* and total nitrogen concentrations; the median concentrations were 560 cfu/100ml and 1.6 g/m³ within the rehabilitation area respectively, compared with 870 cfu/100ml and 1.9 g/m³ upstream. These differences may be explained by the input of the higher quality reference tributary stream between the upstream monitoring site and the site within the rehabilitation area (downstream), (Figure 6.8). This is discussed further in Section 6.5.2.

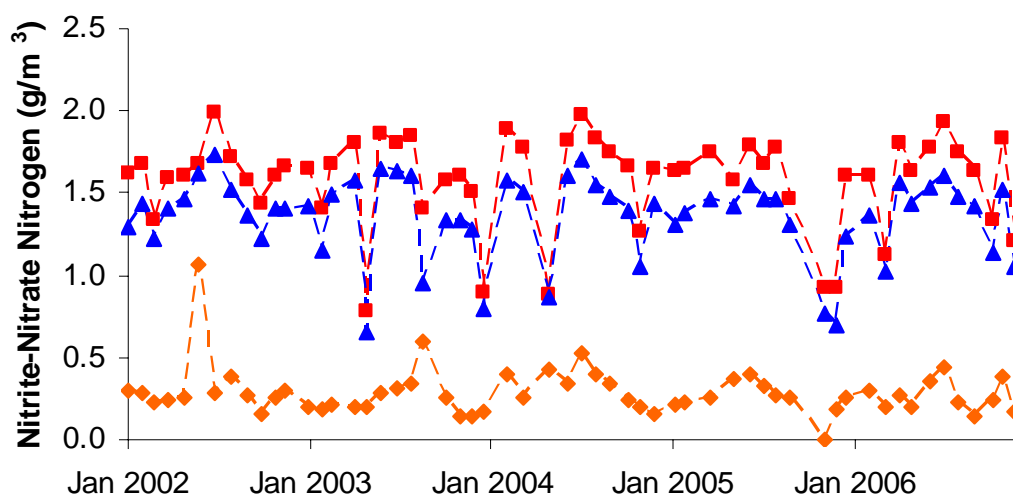


Figure 6.8: Nitrite-nitrate nitrogen concentrations for monitoring sites upstream (red) of and within the rehabilitation area (downstream – blue) as well as the tributary (reference site - orange) that enters the Karori Stream above the downstream monitoring site.

Water temperature monitoring, both monthly spot measurements and continuous monitoring during January 2007, indicated temperatures were higher within the rehabilitation area than the upstream site. For the time period illustrated in Figure 6.9, average daily temperatures and average maximum temperatures were 0.4 °C and 1 °C warmer respectively, within the rehabilitation area. As noted in Section 6.4.1, the upstream site had significantly greater vegetation and therefore shade cover.

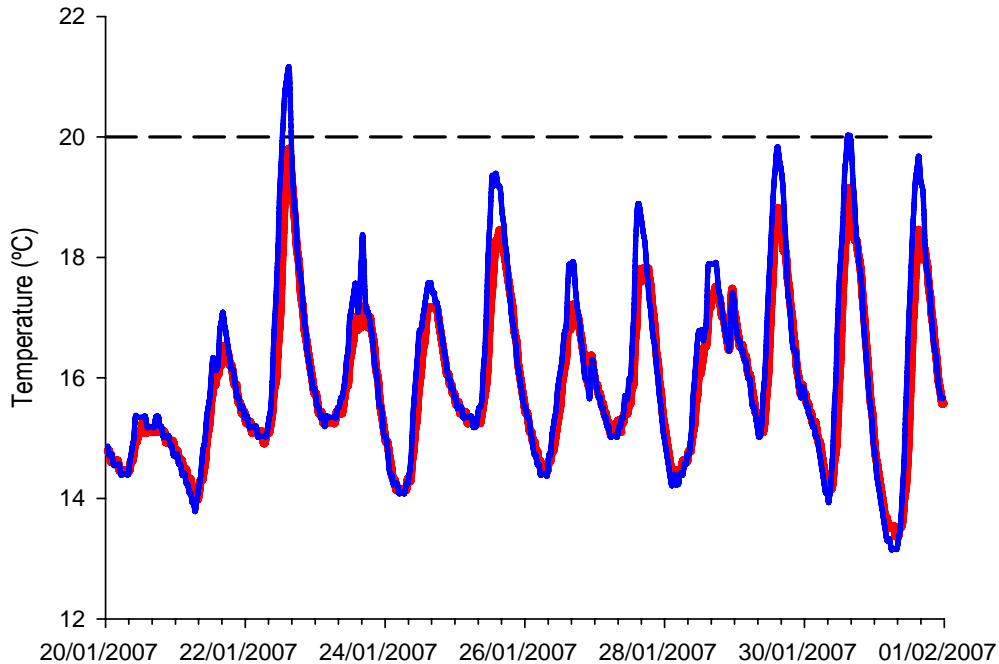


Figure 6.9: Water temperature at sites upstream (red) of and within the rehabilitation area (downstream – blue) on the Karori Stream, based on continuous monitoring during 20 January and 1 February 2007. The dashed line represents the upper thermal tolerance for sensitive invertebrate species (Rutherford et al. 1999).

Significant trends ($p < 0.05$) in water quality are summarised in Table 6.4. Full details of the Seasonal Kendall trend analyses are in Appendix 4. Total kjeldahl nitrogen concentrations increased by 0.019 g/m³ per year within the rehabilitation area (flow-adjusted data only); a similar but greater magnitude trend was present upstream. Upstream of the rehabilitation area concentrations of dissolved reactive phosphorus increased over the reporting period, a trend not observed within the rehabilitation area. The only trend present in data collected from the nearby reference site was a decrease in dissolved reactive phosphorus (0.0008 g/m³ per year).

Table 6.4: Trend slopes (units per year) for raw and flow-adjusted water quality variables that exhibited significant trends ($p < 0.05$) at sites upstream of and within the rehabilitation area on the Karori Stream. NS denotes non-significant (i.e., no trend).

Variable	Upstream		Downstream	
	Raw	Flow-adjusted	Raw	Flow-adjusted
Total Kjeldahl Nitrogen (g/m ³)	0.026	0.020	NS	0.019
Dissolved Reactive Phosphorus (g/m ³)	0.002	0.002	NS	NS

6.4.3 Biological monitoring

(a) Periphyton

Higher periphyton biomass, based on one-off measurements of chlorophyll *a*, was consistently recorded upstream of the rehabilitation area (Figure 6.10). Both sites exceeded the MfE (2000) periphyton biomass guideline for protection of benthic communities ($< 50 \text{ mg/m}^2$) in 2003 and 2007. The upstream site also exceeded this guideline in 2006.

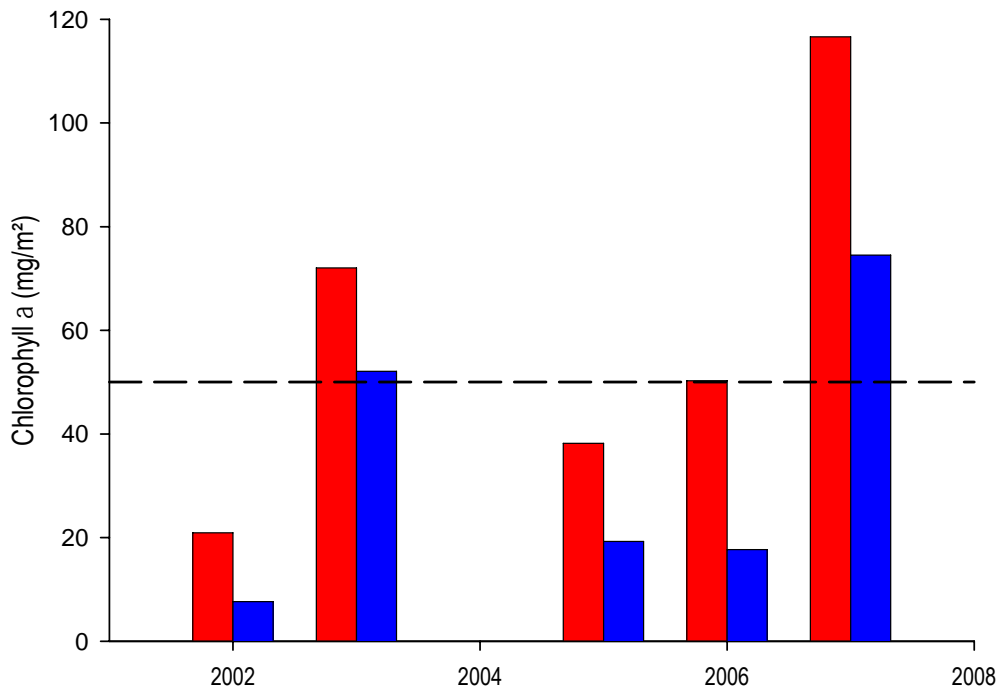


Figure 6.10: Periphyton chlorophyll *a* concentrations measured upstream (red) of and within the rehabilitation area (downstream – blue) of the Karori Stream over 2002 to 2007. Concentrations are based on one-off samples collected annually during the summer months. The black dashed line indicates the MfE (2000) threshold for the protection of benthic biodiversity. No sampling occurred in 2004.

Similarly, monthly visual estimates of streambed periphyton cover more consistently found filamentous periphyton upstream of the rehabilitation area than in it (19 and 13 records respectively). Both sites exceeded MfE (2000) guidelines for filamentous periphyton streambed cover ($< 30\%$ cover) on one occasion.

(b) Macroinvertebrates

Measures of invertebrate community health, MCI, SQMCI, and % EPT taxa scores, were typically slightly higher within the rehabilitation area (Table 6.5). Based on thresholds recommended by Stark & Maxted (2007), invertebrate communities within the Karori Stream can be considered to be in a fairly degraded state. For the reporting period SQMCI and MCI scores for both sites fluctuated between ‘poor’ and ‘fair’.

Table 6.5: Measures of invertebrate health (MCI, SQMCI, and % EPT taxa) for the Karori Stream upstream of and within the rehabilitation area (downstream), based on annual monitoring over 2002 to 2007. The 2002 scores are based on just one sample, with the mean score and standard deviation (SD) for all other years based on three replicate samples. No sampling occurred in 2004.

Year	MCI				SQMCI				% EPT taxa			
	Upstream		Downstream		Upstream		Downstream		Upstream		Downstream	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2002	78.5	-	88.9	-	2.16	-	2.64	-	23.1	-	22.2	-
2003	69.6	8.4	76.7	5.8	2.38	0.1	2.24	0.1	10.2	1.6	17.6	6.6
2005	83.2	5.6	87.3	13.3	2.57	0.4	4.02	0.5	17.7	3.0	22.4	7.7
2006	90.1	1.5	89.6	3.4	3.23	0.3	3.66	0.4	16.4	7.7	24.3	8.2
2007	83.6	6.2	85.6	4.4	3.47	0.3	3.52	0.3	14.0	3.5	26.9	5.8

Spearman rank correlations indicated a statistically significant ($p < 0.05$) increasing trend within the rehabilitation area for % EPT taxa (~ 1.3 % per year – Figure 6.11). SQMCI scores increased (~ 0.26 SQMCI units per year) at the upstream site, however, this trend was not observed within the rehabilitation area. No trends were evident in data collected from the reference site. Full details of the Spearman rank correlations can be found in Appendix 5.

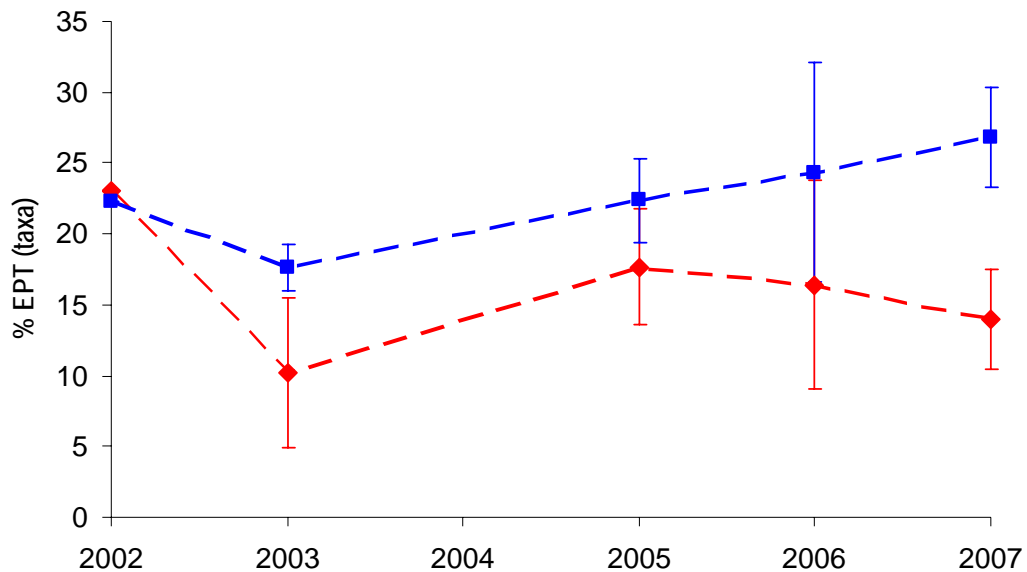


Figure 6.11: Percent EPT taxa scores (± 1 standard error) increased ($p < 0.05$) within the rehabilitation area (downstream - blue) over the reporting period, 2002 to 2007 (1.3 % per year). This trend was not observed upstream (red).

(c) Fish

Fish communities in the Karori Stream were dominated by longfin eels and koaro with shortfin eels, brown trout, upland bullies, and koura found on some sampling occasions but normally in lower numbers (Table 6.6). Koaro (Figure 6.12) were more abundant within the rehabilitation area than the upstream reach on all sampling occasions.

Table 6.6: Fish species (plus koura) found upstream of and within the rehabilitation area (downstream) of the Enaki Stream in 2002, 2003, and 2007. - = absent (0), + = rare (1 - 3), ++ = common (4 - 10), +++ = abundant (10+).

Fish/crustacean	Upstream			Downstream		
	2002	2003	2007	2002	2003	2007
Longfin eel (<i>Anguilla dieffenbachia</i>)	++	+++	-	++	+++	++
Shortfin eel (<i>Anguilla australis</i>)	-	+	-	-	+	-
Koaro (<i>Galaxias brevipinnis</i>)	+	++	+	+++	+++	+++
Brown trout (<i>Salmo trutta</i>)	+	-	-	-	-	-
Upland bully (<i>Gobiomorphus breviceps</i>)	-	-	+	-	-	++



Figure 6.12: Koaro were more abundant within the rehabilitation area but this is thought to be related to instream habitat characteristics rather than riparian rehabilitation.

6.5 Discussion

The benefits of riparian rehabilitation along the banks of a reach of the Karori Stream were always going to be limited by the large proportion of urban land use in the upstream catchment. Urban streams, such as the Karori Stream, consistently record some of the poorest water quality and invertebrate health in the region (e.g., Milne & Perrie 2005, Perrie 2007a).

This study on the effects of riparian rehabilitation on a section of the Karori Stream was further limited by physical differences in the upstream and rehabilitation reaches, the confounding influence of a relatively clean water input from a tributary that joins the Karori Stream between the upstream and downstream monitoring sites, and also by the unsuitability of the upstream reach in representing pre-rehabilitation (or control) conditions. These issues, along with the observed benefits from riparian rehabilitation on physical habitat, water quality and ecosystem health for a reach of the Karori Stream are discussed in the following sections.

6.5.1 Physical habitat

The upstream or “control” reach of the Karori Stream has considerably more vegetation cover (and subsequently streambed shade) than the rehabilitation

area. This makes the upstream reach unsuitable to represent pre-rehabilitation conditions and limits the value of comparisons between reaches. For example, the greater vegetation and shade cover upstream explains the lower median water temperature recorded at the upstream monitoring site.

Streambed shade has not increased within the rehabilitation area; estimates in 2007 are almost identical to those made in 2003 (Warr 2004). Riparian rehabilitation is not a 'quick fix' solution for improving stream health and, as noted in Section 2, it can take many decades to centuries for some of the potential benefits to occur. Streambed shade is anticipated to increase in the future as riparian plants mature and will benefit the health of the Karori Stream by improving the thermal regime and exerting some control over nuisance periphyton growth.

The reach upstream of the rehabilitation area is highly modified, having been straightened and channelised, and contains significant lengths of artificial stream banks reinforced with concrete and gabion baskets. These modifications have created relatively homogenous flow conditions throughout this reach and have reduced habitat diversity. In contrast, the stream reach within the rehabilitation area retains a natural, meandering channel profile and subsequently has a variety of flow conditions and greater habitat diversity (e.g., run, pool and riffle sequences). The differences in habitat diversity between the two reaches probably explain some of the observed differences in aquatic fauna. Furthermore, the modified nature of the upstream reach limits other habitat components such as overhanging vegetation; concrete is not a suitable substrate for vegetation.

6.5.2 Water quality

Water quality is higher within the rehabilitation area, with median concentrations of nutrients and faecal bacteria significantly lower than those upstream. However, this is not likely to be the result of the riparian planting but primarily due to an input of clean water from a tributary that joins the Karori Stream between the upstream monitoring site and the downstream rehabilitation monitoring site.

Water quality did not improve within the rehabilitation area over the reporting period and the overriding influence of urban land use (e.g., stormwater inputs (Figure 6.13) runoff, etc.) will continue to restrict any anticipated benefits. Even with increased dilution of contaminants through the input of clean water from the tributary that enters the Karori Stream, median concentrations of total nitrogen, nitrite-nitrate nitrogen, total phosphorus, dissolved reactive phosphorus and *E. coli* are all above national (ANZECC 2000) water quality guidelines within the rehabilitation area.



Figure 6.13: Stormwater inputs and runoff from the largely urban catchment upstream of the Karori Stream rehabilitation area will continue to limit improvements in water quality that are expected to occur through riparian rehabilitation

6.5.3 Ecosystem health

Periphyton biomass was lower within the rehabilitation area but this is not thought to be related to the riparian rehabilitation but rather caused by the immediate physical habitat and landform surrounding the sampling sites. The most accessible site to sample in the upstream reach happened to be a relatively open spot with limited streambed shade (quite unlike the majority of the upstream reach which has reasonably good riparian cover). In contrast, the sampling site within the rehabilitation reach was deeply incised and gained further shade from the immediate hilly landform. Both sites exceeded MfE (2000) guidelines for the protection of benthic biodiversity over the reporting period and excessive periphyton growth may be reducing habitat quality for aquatic fauna.

Measures of invertebrate community health tended to be slightly higher within the rehabilitation area and may reflect the increased habitat diversity created by the natural meandering channel (pool, riffle, run sequences) and or the improved water quality attributed to the tributary. A small improvement in the proportion of sensitive invertebrate taxa (% EPT taxa) within the rehabilitation area was also observed for the reporting period. However, these small between-site differences and improving trends are of negligible ecological significance and the stream invertebrate community remains in a poor state overall.

Electric fishing results showed koaro to be more abundant within the rehabilitation area. As with the invertebrates, this increased abundance is unlikely related to the riparian rehabilitation, but probably reflects the improved habitat diversity caused by the natural meander of the stream, in particular, the increase in riffle type habitats within this reach. Upstream of the rehabilitation area, the straightened and channelised stream reach has relatively

homogenous flow conditions and lacks the swifter flowing riffle habitats preferred by koaro (McDowall 1990).

Downstream of the rehabilitation area, a 0.5 m ford is likely to be excluding less motile migratory fish from reaching the rehabilitation area. Thus even if improvements in habitat and water quality occur, improvements in fish diversity can be expected to be limited.

6.5.4 Synthesis

As anticipated prior to the commencement of riparian rehabilitation (see Section 2.1.3), the main benefit observed along this reach of the Karori Stream that can be attributed to the rehabilitation programme was an improvement in aesthetic value (refer to Figure 6.3). While water quality, periphyton biomass, invertebrate metrics and fish communities were better within the rehabilitation area, these differences are not considered to be related to the riparian rehabilitation. Rather these differences are associated with the existing differences in the physical morphology of the stream channel and immediate landform or by the tributary that joins the Karori Stream between the two monitoring sites.

Further benefits from riparian rehabilitation may become apparent as the trees and shrubs along the banks of the Karori Stream mature and streambed shade increases. However, improvements in water quality and ecosystem health are always likely to be limited by the overriding impact of pollutants and habitat degradation associated with the predominantly urban land use in the upstream catchment. As it stands, water quality and stream health of the Karori Stream remain in a degraded state.

7. Conclusions and recommendations

Previous studies of riparian rehabilitation have revealed the complexities of rehabilitating stream ecosystems and the difficulties in demonstrating measurable improvements. In this pilot riparian rehabilitation programme, the difficulty in demonstrating beneficial outcomes and linking them to the rehabilitating riparian areas was further exacerbated by one or more of the following:

- additional fencing and planting that occurred immediately upstream of the rehabilitation areas (or wider catchment) during the reporting period;
- tributaries or groundwater entering the streams between the upstream and the rehabilitation area monitoring sites; and/or
- existing differences in physical habitat between the upstream and rehabilitation monitoring reaches.

In addition, rehabilitation of riparian zones is a long-term project and many of the factors that contribute to diverse and healthy ecosystems may take many decades or even centuries to fully develop. The oldest riparian rehabilitation area in this study (the lower Enaki Stream) is still less than 10 years old.

Despite the relatively young age of the three rehabilitation programmes and the study limitations noted above, the results for the 2002-2007 reporting period are encouraging. Both the Enaki and Kakariki streams have shown some improvements in aspects of physical habitat quality and water quality that appear to be reflected in improvements in measures of stream health. In contrast, no improvements in stream health could be attributed to the rehabilitation of the riparian zone along a section of the Karori Stream. This result probably reflects the overriding impact of contaminants and habitat degradation associated with the urban land use that dominates the catchment upstream of the rehabilitation area.

Benefits observed within the riparian rehabilitation areas for the three study streams vary and reflect the different stream types and land use impacts in the upstream catchments. The principal benefits attributable to riparian rehabilitation observed during the report period were:

- improved aesthetic values (Enaki, Kakariki and Karori streams);
- increased vegetation cover and streambed shade (Enaki and Kakariki streams);
- increased bank stability (Enaki and Kakariki streams);
- improved aquatic habitat quality (Enaki and Kakariki streams); and
- reduced water temperatures (Enaki and Kakariki streams).

Other benefits were observed at some sites, such as reduced instream plant growth (Enaki and Kakariki streams), lower nutrient concentrations and sediment inputs (Enaki Stream) and positive changes in macroinvertebrate (Enaki and Kakariki streams) and fish communities (Kakariki Stream). However, it was not always clear whether the observed improvements were

directly linked with the rehabilitating riparian zones or caused by other factors. Nor was it clear in all cases whether these observed improvements necessarily resulted in any significant benefits to the overall health of the stream ecosystem.

Even with the benefits observed from riparian rehabilitation along sections of the three study streams, the streams all remain in a degraded state; elevated concentrations of faecal indicator bacteria and nutrients as well as invertebrate and fish communities dominated by tolerant species are all indicative of poor water quality and stream health overall. Even though the full benefits of riparian rehabilitation along reaches of the Enaki, Kakariki and Karori streams will not become apparent until riparian vegetation matures and canopy closure is achieved, the potential benefits that can be expected from riparian rehabilitation in the future are likely to be limited; all three stream reaches are strongly affected by the overriding impact of agricultural and urban land use within the upstream catchments (e.g., stock access to stream beds, effluent run-off, urban stormwater). For this reason, together with the limitations identified in the existing monitoring programme, it is appropriate to reduce some of the monitoring and focus more attention on addressing some of the issues limiting improvements.

This study has demonstrated that riparian rehabilitation can, in some situations, be a useful tool for mitigating some of the degradation caused by agricultural and urban land use to stream health in the Wellington region. However, it is clear that riparian rehabilitation alone will not address all the issues relating to poor stream health and that further plans and policies need to be developed and implemented, in conjunction with Greater Wellington's Riparian Management Strategy, to address the causes for poor stream health (e.g., farming practices and stormwater management).

7.1 Recommendations for future monitoring

7.1.1 Enaki Stream

- Cease monitoring upstream of the rehabilitation area; this site is no longer representative of pre-rehabilitation conditions.
- Continue monthly water sampling and annual assessments of invertebrate and periphyton communities at the monitoring site within the rehabilitation area, and monitoring of fish communities every three years.

7.1.2 Kakariki Stream

- Cease monitoring upstream of the rehabilitation area; this site is no longer representative of pre-rehabilitation conditions.
- Cease monthly monitoring of water quality variables at the site within the rehabilitation area; groundwater inputs confound interpretation of the monitoring results.

- Continue annual assessments of invertebrate communities and assess fish communities every three years at the monitoring site within the rehabilitation area.

7.1.3 Karori Stream

- Cease all monitoring; improvements related to riparian rehabilitation are considered unlikely. Greater Wellington already monitors a site located approximately halfway between the two riparian monitoring sites as part of the Rivers State of Environment monitoring programme; data from this monitoring site (monthly water quality assessments and annual assessments of invertebrate and periphyton communities) can be used to gauge the impact of riparian rehabilitation in the future.

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9. Acknowledgements

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Appendix 1: Water quality variables and analytical methods

As far as practicable, all monitoring sites were sampled at the same time of the month and at the same time of the day throughout the monitoring period. Water samples are collected in mid stream, on a representative stretch of the stream, usually a run. Over the January 2002 to December 2006 reporting period, water temperature, dissolved oxygen, conductivity and pH measurements were taken in the field. Turbidity, *E. coli*, total organic carbon, and nutrients were analysed in the laboratory. Table A1.1 outlines the key water quality variables and analytical techniques for the reporting period.

Table A1.1: Key water quality variables and methodology

Variable	Method
Temperature (°C)	Field meter measurement and Stowaway tidbit ® loggers (continuous monitoring)
Flow (m ³ /s)	Field gauging
Suspended solids (g/m ³)	APHA 2130 B 20 th ed. 1998
Turbidity (NTU)	APHA 2130 B 20 th ed. 1998
Dissolved Oxygen (g/m ³ and % sat.)	Field meter measurement
pH	Field meter measurement
Conductivity (µs/cm @25°C)	Field meter measurement
Dissolved Reactive Phosphorus (g/m ³)	APHA 4500-PG 20 th ed. 1998
Total Phosphorus (g/m ³)	APHA 4500-P B, E 20 th ed. 1998
Total Ammonia Nitrogen (g/m ³)	APHA 4500-NH ₃ G 20 th ed. 1998
Nitrate Nitrogen (g/m ³)	Calculation
Nitrite Nitrogen (g/m ³)	APHA 4500-NO ₃ I 20 th ed. 1998
Nitrate/nitrite Nitrogen (g/m ³)	APHA 4500-NO ₃ I 20 th ed. 1998
Total Kjeldahl Nitrogen (g/m ³)	APHA 4500-N _{org} D. 20 th ed. 1998
Dissolved Inorganic Nitrogen (g/m ³)	Calculation
Total Nitrogen (g/m ³)	Calculation
Total Organic Carbon (g/m ³)	APHA 5310 B 20 th ed. 1998
<i>E. coli</i> (cfu/100 mL)	APHA 9213 D 20 th ed. 1998

Appendix 2: Water quality, invertebrate and periphyton guidelines

Guidelines used to interpret water quality, invertebrate metrics and periphyton data are outlined in Tables A2.1, A2.2 and A2.3 respectively.

Table A2.1: ANZECC (2000) guidelines used to assess physico-chemical and microbiological aspects of water quality in this report

Variable	Guideline Value	Reference
Nitrite-Nitrate Nitrogen (g/m ³)	≤0.444	ANZECC & ARMCANZ (2000)
Ammoniacal Nitrogen (g/m ³)	≤0.021	ANZECC & ARMCANZ (2000)
Total Nitrogen (g/m ³)	≤0.614	ANZECC & ARMCANZ (2000)
Dissolved Reactive Phosphorus (g/m ³)	≤0.010	ANZECC & ARMCANZ (2000)
Total Phosphorus (g/m ³)	≤0.033	ANZECC & ARMCANZ (2000)
<i>E. coli</i> (cfu/100 mL)	≤100	ANZECC & ARMCANZ (2000)

Table A2.2: Interpretation of MCI-type biotic scores (Stark & Maxted 2007)

Quality Class	MCI	SQMCI
Excellent	> 119	> 5.99
Good	100 - 119	5.00 - 5.90
Fair	80 - 99	4.00 - 4.99
Poor	< 80	< 4.00

Table A3.3: Guidelines used to assess periphyton streambed cover and biomass (MfE 2000)

Instream variable	Instream value	Threshold
Streambed cover (Filamentous periphyton)	Aesthetics/recreation and trout habitat and angling	30 % > 2 cm long
Maximum chlorophyll <i>a</i>	Benthic biodiversity	50 mg/m ²

Appendix 3: Results from Wilcoxon Matched Pairs test

Table A3.1: Enaki Stream

Variable	Z	p
Temperature (°C)	-0.978	0.328
Dissolved Oxygen (% saturation)	-4.172	0.000
Dissolved Oxygen (g/m ³)	-3.665	0.000
pH	-2.239	0.025
Turbidity (NTU)	-2.602	0.009
Total Suspended Solids (g/m ³)	-1.047	0.295
Conductivity (µS/cm)	-1.203	0.229
Total Organic Carbon (g/m ³)	-2.696	0.007
Nitrite-Nitrate Nitrogen	-0.488	0.626
Ammoniacal Nitrogen (g/m ³)	-0.656	0.512
Total Kjeldahl Nitrogen (g/m ³)	-1.883	0.06
Total Nitrogen (g/m ³)	-2.396	0.017
Dissolved Reactive Phosphorus (g/m ³)	0.779	0.436
Total Phosphorus (g/m ³)	-2.364	0.018
<i>E. coli</i> (cfu/100mL)	1.429	0.153

Table A3.2: Kakariki Stream

Variable	Z	p
Temperature (°C)	-1.032	0.302
Dissolved Oxygen (% saturation)	-4.494	0.000
Dissolved Oxygen (g/m ³)	-4.294	0.000
pH	2.583	0.010
Turbidity (NTU)	2.915	0.004
Total Suspended Solids (g/m ³)	-0.974	0.330
Conductivity (µS/cm)	6.454	0.000
Total Organic Carbon (g/m ³)	2.633	0.008
Nitrite-Nitrate Nitrogen	-5.574	0.000
Ammoniacal Nitrogen (g/m ³)	1.368	0.171
Total Kjeldahl Nitrogen (g/m ³)	-0.313	0.754
Total Nitrogen (g/m ³)	-3.757	0.000
Dissolved Reactive Phosphorus (g/m ³)	2.968	0.003
Total Phosphorus (g/m ³)	3.058	0.002
<i>E. coli</i> (cfu/100mL)	-0.195	0.846

Table A3.3: Karori Stream

Variable	Z	p
Temperature (°C)	3.655	0.000
Dissolved Oxygen (% saturation)	4.071	0.000
Dissolved Oxygen (g/m ³)	4.068	0.000
pH	5.195	0.000
Turbidity (NTU)	-4.009	0.000
Total Suspended Solids (g/m ³)	-1.255	0.209
Conductivity (µS/cm)	-0.873	0.383
Total Organic Carbon (g/m ³)	-0.466	0.641
Nitrite-Nitrate Nitrogen	-6.512	0.000
Ammoniacal Nitrogen (g/m ³)	-4.147	0.000
Total Kjeldahl Nitrogen (g/m ³)	-0.749	0.000
Total Nitrogen (g/m ³)	-5.582	0.000
Dissolved Reactive Phosphorus (g/m ³)	-5.478	0.000
Total Phosphorus (g/m ³)	-4.701	0.000
<i>E. coli</i> (cfu/100mL)	-3.854	0.000

Appendix 4: Results of Seasonal Kendall Trend Analysis

Table A4.1: Enaki Stream – upstream (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.788	-2.923	57	< 0.05
Dissolved Oxygen (% saturation)	-1.939	-2.345	55	< 0.05
Dissolved Oxygen (g/m ³)	-0.07818	-0.7147	55	NS
pH	-0.1097	-2.91	48	< 0.05
Turbidity (NTU)	-0.1386	-0.9575	58	NS
Total Suspended Solids (g/m ³)	0	-0.8232	58	NS
Conductivity (µS/cm)	1.239	1.037	54	NS
Total Organic Carbon (g/m ³)	-0.08567	-0.6944	58	NS
Nitrite-Nitrate Nitrogen	-0.02584	-0.7014	56	NS
Ammoniacal Nitrogen (g/m ³)	0	-1.016	58	NS
Total Kjeldahl Nitrogen (g/m ³)	0	-1.378	58	< 0.2
Total Nitrogen (g/m ³)	-0.06771	-1.479	58	< 0.2
Dissolved Reactive Phosphorus (g/m ³)	-0.00063	-0.908	58	NS
Total Phosphorus (g/m ³)	-0.00372	-2.184	58	< 0.05
<i>E. coli</i> (cfu/100mL)	24.04	1.282	57	< 0.2

Table A4.2: Enaki Stream – upstream (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.7371	-2.935	52	< 0.05
Dissolved Oxygen (% saturation)	-2.033	-2.394	50	< 0.05
Dissolved Oxygen (g/m ³)	-0.08848	-0.8854	50	NS
pH	-0.1206	-2.941	44	< 0.05
Turbidity (NTU)	-0.159	-0.8668	53	NS
Total Suspended Solids (g/m ³)	-0.1358	-0.8668	53	NS
Conductivity (µS/cm)	1.057	0.9119	49	NS
Total Organic Carbon (g/m ³)	-0.06061	-0.5081	53	NS
Nitrite-Nitrate Nitrogen	-0.02035	-0.3824	51	NS
Ammoniacal Nitrogen (g/m ³)	-0.00023	-1.285	53	< 0.1
Total Kjeldahl Nitrogen (g/m ³)	-0.01027	-0.269	53	NS
Total Nitrogen (g/m ³)	-0.03532	-0.807	53	NS
Dissolved Reactive Phosphorus (g/m ³)	-0.00024	-0.2092	53	NS
Total Phosphorus (g/m ³)	-0.0041	-2.172	53	< 0.05
<i>E. coli</i> (cfu/100mL)	31.24	1.524	53	< 0.2

Table A4.3: Enaki Stream – downstream (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.6384	-2.711	56	< 0.05
Dissolved Oxygen (% saturation)	-1.069	-1.953	54	< 0.1
Dissolved Oxygen (g/m ³)	-1.069	-1.953	54	< 0.1
pH	-0.1441	-3.379	50	< 0.05
Turbidity (NTU)	-0.1821	-1.43	58	NS
Total Suspended Solids (g/m ³)	0	-1.03	58	NS
Conductivity (µS/cm)	1.992	1.384	55	< 0.2
Total Organic Carbon (g/m ³)	-0.1267	-1.44	58	< 0.2
Nitrite-Nitrate Nitrogen	-0.03237	-0.7292	56	NS
Ammoniacal Nitrogen (g/m ³)	0	-1.456	58	< 0.2
Total Kjeldahl Nitrogen (g/m ³)	0	-1.758	58	< 0.1
Total Nitrogen (g/m ³)	-0.00603	-1.54	57	< 0.2
Dissolved Reactive Phosphorus (g/m ³)	-0.00096	-1.228	58	NS
Total Phosphorus (g/m ³)	-0.00331	-1.97	58	< 0.05
<i>E. coli</i> (cfu/100mL)	19.75	1.447	57	< 0.2

Table A4.4: Enaki Stream – downstream (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.7587	-2.774	51	< 0.05
Dissolved Oxygen (% saturation)	-1.571	-2.087	49	< 0.05
Dissolved Oxygen (g/m ³)	-0.03297	-0.202	49	NS
pH	-0.1514	-3.517	46	< 0.05
Turbidity (NTU)	-0.1303	-1.106	53	NS
Total Suspended Solids (g/m ³)	-0.1624	-0.1624	53	NS
Conductivity (µS/cm)	1.926	1.148	50	NS
Total Organic Carbon (g/m ³)	-0.1089	-1.465	53	< 0.2
Nitrite-Nitrate Nitrogen	-0.01604	-0.2232	51	NS
Ammoniacal Nitrogen (g/m ³)	-0.00122	-1.465	53	< 0.2
Total Kjeldahl Nitrogen (g/m ³)	-0.00588	-1.704	53	< 0.1
Total Nitrogen (g/m ³)	-0.02371	0.7997	52	NS
Dissolved Reactive Phosphorus (g/m ³)	-0.00062	-0.807	53	NS
Total Phosphorus (g/m ³)	-0.003	-1.763	53	< 0.1
<i>E. coli</i> (cfu/100mL)	19.66	1.225	53	NS

Table A4.5: Kakariki Stream – upstream (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	0.07473	0.2244	56	NS
Dissolved Oxygen (% saturation)	-0.09311	-0.02956	54	NS
Dissolved Oxygen (g/m ³)	-0.00767	0	54	NS
pH	-0.02507	-0.9616	51	NS
Turbidity (NTU)	0.7727	2.259	58	< 0.05
Total Suspended Solids (g/m ³)	1.194	2.089	58	< 0.05
Conductivity (µS/cm)	2.83	0.457	55	NS
Total Organic Carbon (g/m ³)	0.4354	1.25	58	NS
Nitrite-Nitrate Nitrogen	0.003374	0.1091	57	NS
Ammoniacal Nitrogen (g/m ³)	0	-0.3493	58	NS
Total Kjeldahl Nitrogen (g/m ³)	0.03339	1.552	58	< 0.2
Total Nitrogen (g/m ³)	0.02427	0.4823	58	NS
Dissolved Reactive Phosphorus (g/m ³)	0.003997	4.366	58	< 0.05
Total Phosphorus (g/m ³)	0.004393	1.675	58	< 0.1
<i>E. coli</i> (cfu/100mL)	71.72	1.33	58	< 0.2

Table A4.6: Kakariki Stream – upstream (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	0.1225	0.4635	52	NS
Dissolved Oxygen (% saturation)	0.5351	0.453	50	NS
Dissolved Oxygen (g/m ³)	0.04033	0.2589	50	NS
pH	-0.02232	-0.8292	48	NS
Turbidity (NTU)	0.6508	2.095	54	< 0.05
Total Suspended Solids (g/m ³)	1.279	2.385	54	< 0.05
Conductivity (µS/cm)	1.112	0.4444	51	NS
Total Organic Carbon (g/m ³)	0.6431	2.211	54	< 0.05
Nitrite-Nitrate Nitrogen	0.00669	0.06004	53	NS
Ammoniacal Nitrogen (g/m ³)	0.001699	0.4073	54	NS
Total Kjeldahl Nitrogen (g/m ³)	0.04354	1.862	54	< 0.1
Total Nitrogen (g/m ³)	0.07132	1.28	54	NS
Dissolved Reactive Phosphorus (g/m ³)	0.003792	4.305	54	< 0.05
Total Phosphorus (g/m ³)	0.003622	1.047	54	NS
<i>E. coli</i> (cfu/100mL)	56.83	0.9309	54	NS

Table A4.7: Kakariki Stream – downstream (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.02951	-0.1123	56	NS
Dissolved Oxygen (% saturation)	2.998	2.15	53	< 0.05
Dissolved Oxygen (g/m ³)	0.3461	2.15	53	< 0.05
pH	-0.03199	-1.154	51	NS
Turbidity (NTU)	-0.5022	-1.17	58	NS
Total Suspended Solids (g/m ³)	-0.329	-0.9472	58	NS
Conductivity (µS/cm)	4.632	1.115	55	NS
Total Organic Carbon (g/m ³)	0.1431	0.3724	58	NS
Nitrite-Nitrate Nitrogen	0.033	0.9038	58	NS
Ammoniacal Nitrogen (g/m ³)	0	0.1074	58	NS
Total Kjeldahl Nitrogen (g/m ³)	0	-0.1634	58	NS
Total Nitrogen (g/m ³)	0.04792	0.8823	58	NS
Dissolved Reactive Phosphorus (g/m ³)	0.004055	4.503	58	< 0.05
Total Phosphorus (g/m ³)	-0.00384	-1.331	58	< 0.2
<i>E. coli</i> (cfu/100mL)	85.5	1.25	58	NS

Table A4.8: Kakariki Stream – downstream (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	0.00063	0	52	NS
Dissolved Oxygen (% saturation)	2.378	2.107	49	< 0.05
Dissolved Oxygen (g/m ³)	0.2256	2.041	49	< 0.05
pH	-0.03016	-1.037	48	NS
Turbidity (NTU)	-0.3712	-1.105	54	NS
Total Suspended Solids (g/m ³)	-0.5172	0.8145	54	NS
Conductivity (µS/cm)	3.344	0.6349	51	NS
Total Organic Carbon (g/m ³)	0.1608	0.4654	54	NS
Nitrite-Nitrate Nitrogen	0.007351	0.1745	54	NS
Ammoniacal Nitrogen (g/m ³)	-0.00011	-0.05818	54	NS
Total Kjeldahl Nitrogen (g/m ³)	-0.00507	-0.2327	54	NS
Total Nitrogen (g/m ³)	0.03858	0.7564	54	NS
Dissolved Reactive Phosphorus (g/m ³)	0.004296	4.073	54	< 0.05
Total Phosphorus (g/m ³)	-0.00699	-2.269	54	< 0.05
<i>E. coli</i> (cfu/100mL)	55.48	0.5818	54	NS

Table A4.9: Kakariki reference site (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.139	-0.8981	56	NS
Dissolved Oxygen (% saturation)	-0.4524	-0.8926	55	NS
Dissolved Oxygen (g/m ³)	-0.06351	-0.1478	54	NS
pH	-0.09756	-0.994	52	NS
Turbidity (NTU)	-0.06871	-0.7707	58	NS
Total Suspended Solids (g/m ³)	0	-1.697	58	< 0.1
Conductivity (µS/cm)	0.5909	-0.08847	54	NS
Total Organic Carbon (g/m ³)	-0.08709	-0.6128	58	NS
Nitrite-Nitrate Nitrogen	0.00847	0.5461	57	NS
Ammoniacal Nitrogen (g/m ³)	-0.00247	-2.716	58	< 0.05
Total Kjeldahl Nitrogen (g/m ³)	0	0.3685	58	NS
Total Nitrogen (g/m ³)	0	0.8788	58	NS
Dissolved Reactive Phosphorus (g/m ³)	-0.0005	-0.8015	58	NS
Total Phosphorus (g/m ³)	-0.00012	-0.2133	58	NS
<i>E. coli</i> (cfu/100mL)	5.015	0.49	57	NS

Table A4.10: Kakariki reference site (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.1102	-0.6188	52	NS
Dissolved Oxygen (% saturation)	0.3807	0.127	51	NS
Dissolved Oxygen (g/m ³)	0.04734	0.5506	50	NS
pH	-0.05238	-0.67	49	NS
Turbidity (NTU)	-0.04833	-0.4073	54	NS
Total Suspended Solids (g/m ³)	-0.1019	-1.338	54	< 0.2
Conductivity (µS/cm)	-0.1619	0.03288	50	NS
Total Organic Carbon (g/m ³)	-0.1809	-1.396	54	< 0.2
Nitrite-Nitrate Nitrogen	0.0186	1.861	53	< 0.1
Ammoniacal Nitrogen (g/m ³)	-0.00302	-2.795	54	< 0.05
Total Kjeldahl Nitrogen (g/m ³)	-0.00039	0	54	NS
Total Nitrogen (g/m ³)	0.026	1.338	54	< 0.2
Dissolved Reactive Phosphorus (g/m ³)	-0.00061	-0.5818	54	NS
Total Phosphorus (g/m ³)	-0.00052	-0.4073	54	NS
<i>E. coli</i> (cfu/100mL)	4.415	0.5081	53	NS

Table A4.11: Karori Stream – upstream (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.08658	-0.7481	55	NS
Dissolved Oxygen (% saturation)	-0.3242	-0.60953	53	NS
Dissolved Oxygen (g/m ³)	0.02188	0.3042	53	NS
pH	-0.08422	-1.948	48	< 0.1
Turbidity (NTU)	0.03098	0.2457	57	NS
Total Suspended Solids (g/m ³)	0	0.4622	56	NS
Conductivity (µS/cm)	1.326	0.2571	55	NS
Total Organic Carbon (g/m ³)	0	-0.02742	57	NS
Nitrite-Nitrate Nitrogen	-0.01012	-0.6559	57	NS
Ammoniacal Nitrogen (g/m ³)	0.0007908	1.947	57	< 0.1
Total Kjeldahl Nitrogen (g/m ³)	0.02609	3.425	57	< 0.05
Total Nitrogen (g/m ³)	0	0.1943	57	NS
Dissolved Reactive Phosphorus (g/m ³)	0.002466	2.598	57	< 0.05
Total Phosphorus (g/m ³)	0.00214	1.422	57	< 0.2
<i>E. coli</i> (cfu/100mL)	40.73	0.464	57	NS

Table A4.12: Karori Stream – upstream (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.03858	-0.3186	51	NS
Dissolved Oxygen (% saturation)	-0.2459	-0.5251	50	NS
Dissolved Oxygen (g/m ³)	0.03132	0.3843	51	NS
pH	-0.07238	-1.63	44	< 0.2
Turbidity (NTU)	0.03155	0.5446	53	NS
Total Suspended Solids (g/m ³)	0.003311	0.5446	53	NS
Conductivity (µS/cm)	2.663	0.7686	51	NS
Total Organic Carbon (g/m ³)	-0.00653	0	53	NS
Nitrite-Nitrate Nitrogen	-0.01428	-0.3631	53	NS
Ammoniacal Nitrogen (g/m ³)	0.001876	1.815	53	< 0.1
Total Kjeldahl Nitrogen (g/m ³)	0.01997	3.026	53	< 0.05
Total Nitrogen (g/m ³)	-0.005278	-0.06051	53	NS
Dissolved Reactive Phosphorus (g/m ³)	0.001673	1.997	53	< 0.05
Total Phosphorus (g/m ³)	0.001032	0.9077	53	NS
<i>E. coli</i> (cfu/100mL)	14.1	0.06051	53	NS

Table A4.13: Karori Stream – downstream (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	0.01038	0.2184	57	NS
Dissolved Oxygen (% saturation)	0.682	0.7602	53	NS
Dissolved Oxygen (g/m ³)	0.05486	0.769	54	NS
pH	-0.06835	-1.623	50	< 0.2
Turbidity (NTU)	0.01038	0.2184	57	NS
Total Suspended Solids (g/m ³)	0	-0.3183	57	NS
Conductivity (µS/cm)	0.7583	0.1999	55	NS
Total Organic Carbon (g/m ³)	0	-0.1917	57	NS
Nitrite-Nitrate Nitrogen	-0.02009	-1.429	56	< 0.2
Ammoniacal Nitrogen (g/m ³)	0	1.192	57	NS
Total Kjeldahl Nitrogen (g/m ³)	0	2.682	57	< 0.05
Total Nitrogen (g/m ³)	0	-0.1387	57	NS
Dissolved Reactive Phosphorus (g/m ³)	0.001707	1.676	57	< 0.1
Total Phosphorus (g/m ³)	0.0007411	0.1957	56	NS
<i>E. coli</i> (cfu/100mL)	9.437	0.1637	57	NS

Table A4.14: Karori Stream – downstream (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	0.003388	0	52	NS
Dissolved Oxygen (% saturation)	0.8399	1.149	50	NS
Dissolved Oxygen (g/m ³)	0.06362	1.081	51	NS
pH	-0.01909	-0.7401	46	NS
Turbidity (NTU)	-0.01764	-0.2421	53	NS
Total Suspended Solids (g/m ³)	-0.002209	-0.06051	53	NS
Conductivity (µS/cm)	0.9775	0.1922	51	NS
Total Organic Carbon (g/m ³)	0.01956	0.121	53	NS
Nitrite-Nitrate Nitrogen	-0.02179	-1.282	52	NS
Ammoniacal Nitrogen (g/m ³)	9.855E-05	0.3631	53	NS
Total Kjeldahl Nitrogen (g/m ³)	0.01882	1.997	53	< 0.05
Total Nitrogen (g/m ³)	-0.000706	0	53	NS
Dissolved Reactive Phosphorus (g/m ³)	0.0009326	1.21	53	NS
Total Phosphorus (g/m ³)	1.825E-05	0.06051	53	NS
<i>E. coli</i> (cfu/100mL)				

Table A4.15: Karori reference site (raw data)

Variable	Slope	Z	n	p
Temperature (°C)	-0.07778	0.5613	56	NS
Dissolved Oxygen (% saturation)	-0.4088	-1.03	53	NS
Dissolved Oxygen (g/m ³)	0.02874	0.333	53	NS
pH	-0.08616	-1.788	50	< 0.1
Turbidity (NTU)	-0.1138	-1.774	57	< 0.1
Total Suspended Solids (g/m ³)	0	-1.011	57	NS
Conductivity (µS/cm)	1.759	0.6292	55	NS
Total Organic Carbon (g/m ³)	-0.05982	-1.042	57	NS
Nitrite-Nitrate Nitrogen	-0.004263	-0.5314	56	NS
Ammoniacal Nitrogen (g/m ³)	0	0.1392	57	NS
Total Kjeldahl Nitrogen (g/m ³)	0	0.1175	57	NS
Total Nitrogen (g/m ³)	0	-0.4903	57	NS
Dissolved Reactive Phosphorus (g/m ³)	-0.00099	-1.713	57	< 0.1
Total Phosphorus (g/m ³)	-0.000971	-0.9571	57	NS
<i>E. coli</i> (cfu/100mL)	1.198	1.348	56	< 0.2

Table A4.16: Karori reference site (flow-adjusted data)

Variable	Slope	Z	n	p
Temperature (°C)	0.02354	0.1552	52	NS
Dissolved Oxygen (% saturation)	-0.2258	-0.3889	50	NS
Dissolved Oxygen (g/m ³)	0.01448	0.2592	50	NS
pH	-0.04646	-1.554	46	< 0.2
Turbidity (NTU)	-0.1513	-1.755	53	< 0.1
Total Suspended Solids (g/m ³)	-0.04909	-1.393	53	< 0.2
Conductivity (µS/cm)	2.391	0.7046	51	NS
Total Organic Carbon (g/m ³)	-0.04117	-0.6656	53	NS
Nitrite-Nitrate Nitrogen	-0.005504	-0.8732	52	NS
Ammoniacal Nitrogen (g/m ³)	-5.11E-05	-0.6056	53	NS
Total Kjeldahl Nitrogen (g/m ³)	0.0001716	0.1815	53	NS
Total Nitrogen (g/m ³)	-0.009005	-1.029	53	NS
Dissolved Reactive Phosphorus (g/m ³)	-0.000848	-1.997	53	< 0.05
Total Phosphorus (g/m ³)	-0.00095	-0.7867	53	NS
<i>E. coli</i> (cfu/100mL)	1.774	1.153	52	NS

Table A4.17: Temperature trends from Rivers State of the Environment monitoring sites near the Enaki Stream

Site No.	Site Name	slope	Z	n	p
RS49	Beef Creek at headwaters	0.448	1.369	39	<0.2
RS50	Mangatarere Stream at SH2	0.684	3.037	59	<0.05

Appendix 5: Results of Spearman rank correlations

Metric	Enaki Upstream		Enaki Downstream	
	Spearman correlation	ρ	Spearman correlation	ρ
MCI	0.429	NS	-0.257	NS
SQMCI	-0.143	NS	-0.029	NS
% EPT taxa	0.464	NS	-0.143	NS

Metric	Kakariki Upstream		Kakariki Downstream	
	Spearman correlation	ρ	Spearman correlation	ρ
MCI	0.943	< 0.05	-0.143	NS
SQMCI	0.943	< 0.05	-0.086	NS
% EPT taxa	0.880	< 0.05	0.982	< 0.05

Metric	Karori Upstream		Karori Downstream	
	Spearman correlation	ρ	Spearman correlation	ρ
MCI	0.800	NS	0.000	NS
SQMCI	1.000	< 0.05	0.500	NS
% EPT taxa	-0.400	NS	0.900	< 0.05

Appendix 6: Karori and Kakariki reference site data summaries

Kakariki reference site

Water quality at the Kakariki reference site shows signs of moderate degradation (Table A6.1) with median concentrations of faecal bacteria (*E. coli*) and dissolved reactive phosphorus exceeding national water quality guidelines (ANZECC 2000). This degradation probably reflects the urban land use in the upstream catchment. The only trend apparent in water quality data over the reporting period was a decrease in ammoniacal nitrogen concentrations which represents a slight improvement in water quality (Table A6.2).

Table A6.1: Summary of physico-chemical and microbiological water quality data, based on monthly monitoring over January 2002 to December 2006

Variable	Median	Min	Max	<i>n</i>
Temperature (°C)	14.49	9	22.5	56
Dissolved Oxygen (% saturation)	97	75.5	126	55
Dissolved Oxygen (g/m ³)	10.2	6.9	12.8	54
pH	7.73	5.22	10.2	52
Turbidity (NTU)	2.08	0.78	59.8	58
Total Suspended Solids (g/m ³)	1.5	1.5	37	58
Conductivity (µS/cm)	215.5	67	476	54
Total Organic Carbon (g/m ³)	2.3	0.5	6.7	58
Nitrite-Nitrate Nitrogen	0.182	0.003	1.01	57
Ammoniacal Nitrogen (g/m ³)	0.01	0.005	0.21	58
Total Kjeldahl Nitrogen (g/m ³)	0.2	0.05	0.7	58
Total Nitrogen (g/m ³)	0.4	0.1	1.3	58
Dissolved Reactive Phosphorus (g/m ³)	0.025	0.002	0.059	58
Total Phosphorus (g/m ³)	0.037	0.018	0.214	58
<i>E. coli</i> (cfu/100 mL)	170	10	8,640	57

Table A6.2: Trend slopes (units per year) for raw and flow-adjusted water quality variables that exhibited significant trends ($p < 0.05$). NS denotes non-significant (i.e., no trend).

Variable	Raw data	Flow-adjusted data
Temperature (°C)	NS	NS
Dissolved Oxygen (% saturation)	NS	NS
Dissolved Oxygen (g/m ³)	NS	NS
pH	NS	NS
Turbidity (NTU)	NS	NS
Total Suspended Solids (g/m ³)	NS	NS
Conductivity (µS/cm)	NS	NS
Total Organic Carbon (g/m ³)	NS	NS
Nitrite-Nitrate Nitrogen	NS	NS
Ammoniacal Nitrogen (g/m ³)	-0.002466	-0.00302
Total Kjeldahl Nitrogen (g/m ³)	NS	NS
Total Nitrogen (g/m ³)	NS	NS
Dissolved Reactive Phosphorus (g/m ³)	NS	NS
Total Phosphorus (g/m ³)	NS	NS
<i>E. coli</i> (cfu/100 mL)	NS	NS

Invertebrate metric scores indicate that the stream is in a degraded state and can probably be classed as being in a 'fair' condition at best (Table A6.3). Stream invertebrate health may also be deteriorating as SQMCI scores declined over the reporting period (Table A6.4). The degraded invertebrate community probably reflects the upstream urban land use along with the very low flows experienced during summer periods.

Table A6.3: Measures of invertebrate health (MCI, SQMCI, and % EPT taxa), based on annual monitoring over 2002 to 2007. The 2002 scores are based on just one sample, with the mean score and standard deviation (SD) for all other years based on three replicate samples.

Year	MCI		SQMCI		%EPT taxa	
	Mean	SD	Mean	SD	Mean	SD
2002	72.5	0	4.7	0	6.3	0
2003	81.1	10.0	4.9	0	17.3	16.5
2004	89.3	5.3	3.9	0.5	34.0	9.4
2005	90.0	6.2	4.0	0.5	26.0	2.8
2006	85.8	2.7	3.5	0.5	26.2	5.4
2007	80.3	11.7	2.6	1.1	17.1	4.0

Table A6.4: Results from Spearman rank correlations. NS denotes a non-significant trend.

Metric	Kakariki reference site	
	Spearman correlation	ρ
MCI	0.257	NS
SQMCI	-0.886	< 0.05
% EPT taxa	0.257	NS

Karori reference site

Monitoring of water quality at the Karori reference site indicates relatively pristine water quality (Table A6.5) with only median concentrations of dissolved reactive phosphorus exceeding national water quality guidelines (ANZECC 2000). Concentrations of dissolved reactive phosphorus decreased slightly over the reporting period (0.0008 g/m^3) (Table A6.6).

As indicated by the invertebrate metric scores presented in Table A6.7, stream invertebrate health is 'excellent' with a good proportion of the community comprising pollution sensitive species (EPT taxa). The invertebrate community remained in a steady condition over the reporting period (Table A6.8).

Table A6.5: Summary of physico-chemical and microbiological water quality data, based on monthly monitoring over January 2002 to December 2006

Variable	Median	Min	Max	<i>n</i>
Temperature (°C)	10.84	6.81	19.34	56
Dissolved Oxygen (% saturation)	95.6	75.6	122.9	53
Dissolved Oxygen (g/m ³)	10.5	8.38	13.3	53
pH	7.32	5.2	10.88	50
Turbidity (NTU)	1.35	0.34	36	57
Total Suspended Solids (g/m ³)	1.5	1.5	48	54
Conductivity (µS/cm)	224	121	468	55
Total Organic Carbon (g/m ³)	1.4	0.5	11.4	57
Nitrite-Nitrate Nitrogen	0.255	0.007	1.07	56
Ammoniacal Nitrogen (g/m ³)	0.005	0.005	0.03	57
Total Kjeldahl Nitrogen (g/m ³)	0.1	0.05	0.9	57
Total Nitrogen (g/m ³)	0.4	0.1	1.3	57
Dissolved Reactive Phosphorus (g/m ³)	0.022	0.011	0.052	57
Total Phosphorus (g/m ³)	0.028	0.014	0.197	57
<i>E. coli</i> (cfu/100ml)	12	1	340	56

Table A6.6: Trend slopes (units per year) for raw and flow-adjusted water quality variables that exhibited significant trends ($p < 0.05$). NS denotes non-significant (i.e., no trend).

Variable	Raw data	Flow-adjusted data
Temperature (°C)	NS	NS
Dissolved Oxygen (% saturation)	NS	NS
Dissolved Oxygen (g/m ³)	NS	NS
pH	NS	NS
Turbidity (NTU)	NS	NS
Total Suspended Solids (g/m ³)	NS	NS
Conductivity (µS/cm)	NS	NS
Total Organic Carbon (g/m ³)	NS	NS
Nitrite-Nitrate Nitrogen	NS	NS
Ammoniacal Nitrogen (g/m ³)	NS	NS
Total Kjeldahl Nitrogen (g/m ³)	NS	NS
Total Nitrogen (g/m ³)	NS	NS
Dissolved Reactive Phosphorus (g/m ³)	NS	-0.000848
Total Phosphorus (g/m ³)	NS	NS
<i>E. coli</i> (cfu/100mL)	NS	NS

Table A6.7: Measures of invertebrate health (MCI, SQMCI, and % EPT taxa), based on annual monitoring over 2002 to 2007. The 2002 scores are based on just one sample, with the mean score and standard deviation (SD) for all other years based on three replicate samples.

Year	MCI		SQMCI		%EPT taxa	
	Mean	SD	Mean	SD	Mean	SD
2002	126.4	0	5.38	0	40.9	0
2003	143.7	2.63	7.17	0.41	59.1	5.32
2005	129.1	6.08	7.20	0.22	55.6	4.12
2006	134.3	8.18	7.14	0.23	53.2	7.32
2007	130.5	1.95	7.27	0.28	52.3	3.52

Table A6.8: Results from Spearman rank correlations.
NS denotes a non-significant trend.

Metric	Karori reference	
	Spearman correlation	ρ
MCI	0.300	NS
SQMCI	0.700	NS
% EPT taxa	0.000	NS

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Karori Stream at Makara Peak
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