# Ecological effects of flood management activities in Wairarapa Rivers

December 2013

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# EXECUTIVE SUMMARY

*Context*

- Greater Wellington Regional Council (GWRC) has a responsibility to manage the region’s waterways for a number of purposes including flood protection and maintenance of aquatic ecosystem health. As part of their river management, GWRC have commissioned this research to evaluate the ecological effects of current river management practices.
- The research involved sampling fish, macroinvertebrate and periphyton assemblages exposed to three flood management activities in stretches of the Waingawa, Waiohine and Ruamahanga Rivers from September 2012 to May 2013. Monitoring involved pre- and post- works sampling in a full Before After Control Treatment (BACI) design.
- The works included 100-150 m of bed recontouring[1], coupled with some beach disturbance in the Waingawa River, and the installation of rock groynes and bed recontouring along 80 -100 m reaches in the Waiohine and Ruamahanga Rivers. The sites were chosen with consideration that this range of work is representative of the types of in-stream work that is undertaken under the suite of resource consents held by GWRC for implementing the respective flood protection schemes; and for logistical purposes of site access and timing of works.

*Aim and Scope*

- The aim of the research was to assess the potential effects of current river management practices to ensure future river works are undertaken in a way that provides for the sustainable management of Greater Wellington’s rivers and streams.
- Specifically this report provides an assessment of the ecological effects of three flood protection works carried out in the Waingawa, Waiohine and Ruamahanga Rivers in 2012 and 2013.

*Assessment undertaken*

- Reaches (between 80 – 150 m) within each of the rivers where works were undertaken were sampled at three locations: 1. upstream of the proposed works area (to act as a control of any non-work changes); 2. in works area and 3. downstream of the proposed works area.

[1] “bed recontouring” is the term used in the suite of resource consents applicable to this report. Common synonyms are “channel realignment” or “cross blading”.

- Electrofishing of benthic fish, macroinvertebrate sampling, assessment of periphyton biomass, deposition of sediment and any changes in habitat characteristics were undertaken at the three sites immediately before and after the works, and following the first fresh (a "fresh" - in simple terms would be less than 50% flow of an annual flood event) .

*Conclusions*

- Weight of evidence from all 3 studies strongly indicates a less than minor effect on riverine ecology of the engineering activities we investigated. It would thus be reasonable to assume that similar works in other reaches of these types of Wairarapa rivers would have less than minor effects.
- This can be attributed to a number of factors including the activities were relatively small (80 – 150 m length of river works) and discrete (no consideration of cumulative effects was made), this type of activity (despite the increased turbidity and substrate movement) is not dramatically dissimilar to the physical effects of a fresh or flood, which are common in all three rivers, and that such activities have occurred in these rivers (along with other anthropogenic disturbances) for many years.
- Effects scaled with the size of the engineering activity, so that the Waingawa River study which had the greatest length and severity of works, exhibited the biggest ecological effect. Although, even here the number of macroinvertebrates and trout were the only biological parameters that were still "affected" at the final sampling after the first major fresh.
- The scale effect may be particularly important when the cumulative effects of these engineering activities are considered (which we did not do in this study) and it is thus important that although localised effects may not occur, a wider river perspective must be maintained. To that end activities, such as using boulder groynes, leaving and creating backwaters, and minimising the on-site vehicle activity foot print is extremely important.
- Directly after the works biological communities changed, periphyton biomass was reduced and deposited sediment did accumulate. However, the first major fresh or flood reset the local habitat and biological communities, so that the ecological impact of the works essentially disappeared.

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# 1. Introduction

## 1.1. Background

Greater Wellington Regional Council (GWRC) has a responsibility to manage the region's waterways for a number of purposes including flood protection and the maintenance of aquatic ecosystem health.

As part of their river management, GWRC have undertaken a range of programs designed to evaluate current river management practices. Information has been collated on fish present in four Wairarapa river catchments subject to river management (the Waipoua, Waingawa, Waiohine and Upper Ruamahanga Rivers) and used to identify areas where there may be research gaps. This was completed in September 2012 (Death *et al.*, 2012). The second program investigated the effects of three specific flood management activities on the fish, macroinvertebrate, periphyton and deposited sediment in stretches of the Waingawa, Waiohine and Ruamahanga Rivers between September 2012 and May 2013. Monitoring involved pre- and post- works sampling to assess the impacts of flood protection works and is the focus of this report.

## 1.2. Potential effects of river management works

Flood protection works in general have the <u>potential</u> to cause alteration of the habitat, by:

- Changes to stream channel shape and geomorphology;
- Changes to the compaction and size distribution of the stream substrate;
- The mobilisation, re-suspension and increased deposition of fine sediment and associated effects on water clarity and benthic habitat,
- Physical disturbance of, or change of in-stream and riparian habitat,
- Increases in stream bed-level light associated with removal of riparian vegetation, and with potential flow-on effects on water temperature and periphyton abundance.
- Physical destruction of plants and animals;
- Causing animals to migrate from or to the area.

These effects, alone or in combination, have the potential to affect the structure and/or abundance of periphyton, macroinvertebrate and fish communities and the overall ecological health of a river or river segment. These changes may be both deleterious (e.g., increased deposited sediment, loss of pools) and/or beneficial (e.g., reduction in substrate armouring, creation of refugia).

## 1.3. Aim and scope

The aim of this report is to provide an assessment of the effects of flood protection works carried out in the Waingawa, Waiohine and Ruamahanga Rivers, in particular:

- To assess the potential and actual effects of flood control works undertaken and to provide recommendations for future management of these works. The site-specific data and information collected as part of the re-colonisation surveys in each river will constitute the key basis for our recommendations.
- To provide a wider application of the findings from these surveys to other rivers in the GWRC region is also considered.
- To evaluate current river management practice tools or methodologies which can be used to ensure future river works are undertaken in a way that provides for the sustainable management of Greater Wellington's rivers and streams.

# 2. Methods for assessment

## 2.1. Sites assessed

Reaches within each of the Waingawa, Waiohine and Ruamahanga Rivers were identified by GWRC's Flood Protection team as areas where flood control works were to be carried out. The methodology adopted was to visit each river on three separate occasions, once prior to works being carried out, once immediately following the works and then approximately 2-4 weeks later, following a fresh.

Site visits were undertaken on the Waingawa River between November and December 2012, on the Waiohine River between September 2012 and November 2012 and on the Upper Ruamahanga River between February and May 2013. Macroinvertebrate monitoring, electro-fishing and assessment of periphyton and deposited sediment were undertaken at three sites on each river (upstream of the works area, in the works area and downstream of the works area) on three separate occasions.

The aim was to have upstream and downstream reaches that were as similar in habitat potential, hydrology and geomorphology as the engineered reach, within reasonable proximity, to act as controls. However, the very nature of reaches that require engineering is that they differ in hydrology and geomorphology from the rest of the river. The adoption of a Before After Control Impact (BACI) experimental design does assist with mitigating these effects but it does not preclude them completely. For example the potential extra fish habitat created by the placement of rock groynes at some sites (and the backwater at the Waingawa River) was not assessed as neither upstream nor downstream reaches had habitat with undercut banks or backwater suitable for such habitat to make the comparison. Furthermore engineered reaches often had deeper, slower flowing habitat with higher levels of deposited sediment that are less suitable for many biota, thus they were already in a condition of low diversity and abundance of biota. It is important to keep these criteria and caveats in perspective when evaluating the outcomes of the study.

Approximate locations of each study area are shown in Figure 1.

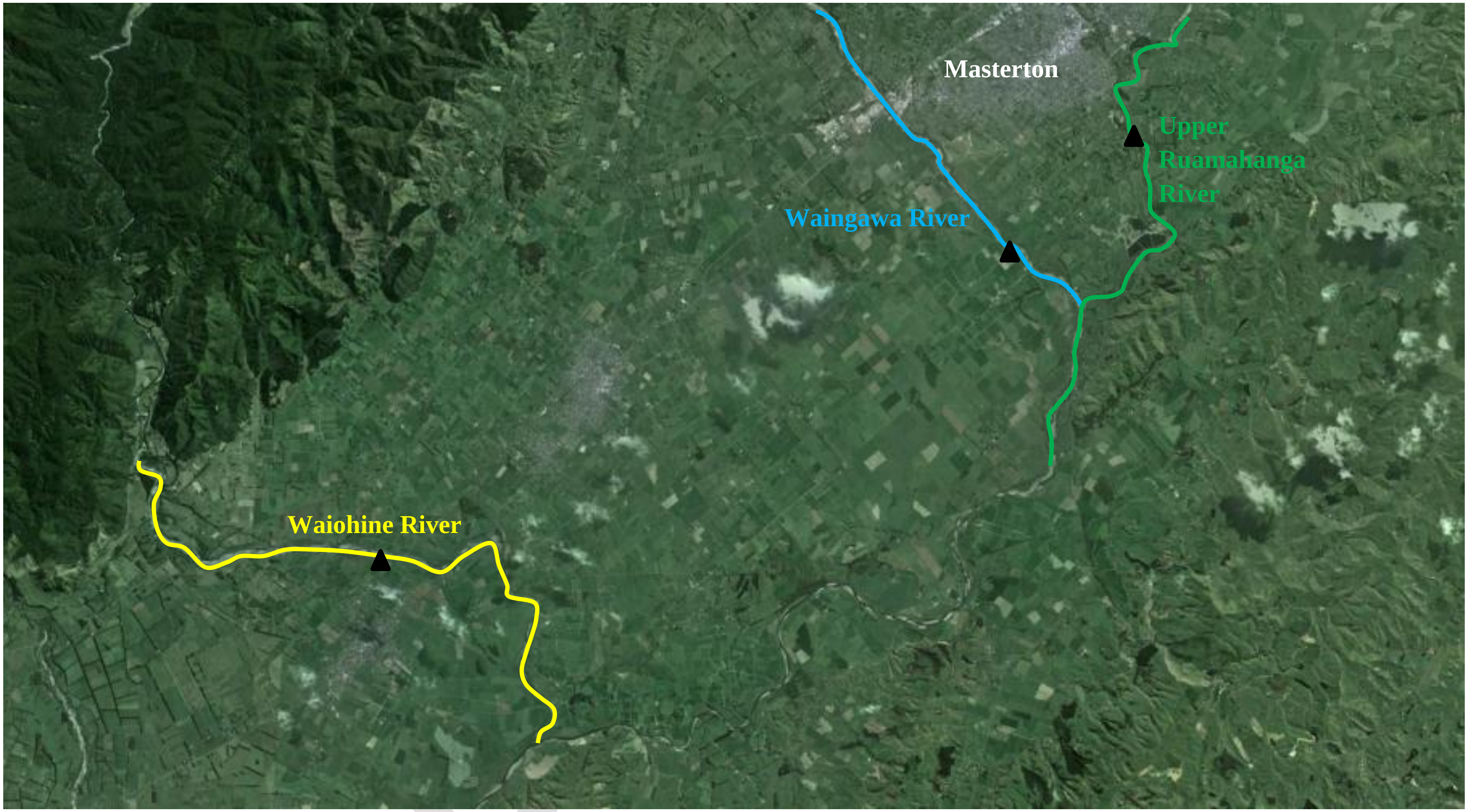



**Figure 1**: Map showing locations of rivers included in re-colonisation surveys following river management works undertaken by GWRC, 2012-2013. Black triangles mark approximate locations of works in the rivers.

## 2.2. Macroinvertebrate sampling

Macroinvertebrate samples, were collected from riffle areas, or where these were absent, from runs. Riffle areas are generally considered to be species rich and have communities that provide good baseline data upon which to assess water quality trends (Winterbourn, 1985). Furthermore, many of the indices adopted for using invertebrates in water quality assessment are only appropriate for riffle habitats (Stark, 1993).

From these riffle areas, five replicate 0.1 $m^2$ Surber samples (250 μm mesh) were collected at each site and stored in 70% isopropanol. In the laboratory, samples were filtered through a 500 μm sieve and invertebrates collected in the sieve were identified and counted. Where possible, invertebrates were identified to species level using available keys. If taxa could not be named, they were differentiated (as per Protocols C3, P3 and QC3 (Stark *et al*, 2001)).

## 2.3. Fish monitoring

Reaches of approximately 600 - 800 $m^2$ were fished at each of the study locations using a Kainga™ EFM300 battery powered backpack electric fishing machine (EFM) following a variant of the protocols of Joy *et al*.(2013). Engineering manipulations were applied to reaches of 80 – 100 m thus to examine the potential effects of the activities, fishing at control and engineered sites was restricted to these same lengths. Depth and velocity precluded safe fishing of the entire channel width, so fishing was conducted to the maximum achievable depth (usually 4 – 6 net widths of 1.5 m each) from the water edge. As the focus was to compare the three reaches at each river, sampling effort was usually dictated by the length of habitat that could be sampled at each engineered reach. Thus the engineered site set the minimum area of habitat sampled and this same area was sampled at the upstream and downstream reaches to allow direct comparison.

Taxa were identified to species level were possible, although fish collected were often juveniles and not easily classified to species. Many species were only collected in low numbers so most were pooled to genus for statistical analysis. Fish length was not recorded.

## 2.4. Deposited sediment

Deposited sediment samples were collected at three sites (upstream of the works area, in the works area and downstream of the works area) from all three rivers, on each sampling occasion.

One background and five replicate Quorer samples were collected following the New Zealand sediment monitoring protocols (Clapcott *et al.*, 2011). Samples collected from each site were frozen for later analysis of Suspended and Volatile Solids. Samples were filtered on pre-weighed GFC glass fibre filters, dried to constant weight and then ashed at 500°C for 4 hours. Filter weights were corrected for background turbidity and sample volume following Quinn http://www.niwa.co.nz/our-science/freshwater/tools/quorer.

## 2.5. Periphyton sampling

Monitoring for periphyton was undertaken at the same time as macroinvertebrate sampling. Five stones were collected from each site alongside each Surber sample and frozen for later analysis of periphyton biomass. Periphyton analysis for Chlorophyll *a* was undertaken by soaking the stones in 90% acetone for 24 h at 5°C in the dark to extract pigments. Absorbency readings were taken using a Cary 50$^{TM}$ Conc UV-Visible spectrophotometer. Chlorophyll *a* was calculated using the method of Steinman and Lamberti (1996). Measures were corrected for stone surface area following (Graham *et al.* 1988) and assuming only the top half of the stone was exposed to light and thus suitable for periphyton growth. At each site a visual assessment was also made of the amount of algae cover on the substrate.

The results were compared with the New Zealand periphyton guidelines (Biggs, 2000), presented in Table 1.



**Table 1:** Provisional biomass and cover guidelines for periphyton growing in gravel/cobble bed streams for three main instream values. Reproduced from Table 14 Ministry for the Environment guidelines (Biggs & Kilroy, 2000).

| Instream value/variable | Diatoms/cyanobacteria | Filamentous algae |
|---|---|---|
| ***Aesthetics/recreation (1 November – 30 April)*** | | |
| Maximum cover of visible stream bed | 60 % > 0.3 cm thick | 30% > 2 cm long |
| Maximum chlorophyll a (mg/m$^2$) | N/A | 120 |
| ***Benthic biodiversity*** | | |
| Mean monthly chlorophyll a (mg/m$^2$) | 15 | 15 |
| Maximum chlorophyll a (mg/m$^2$) | 50 | 50 |
| ***Trout habitat and angling*** | | |
| Maximum cover of whole stream bed | N/A | 30% > 2 cm long |
| Maximum chlorophyll a (mg/m$^2$) | 200 | 120 |

## 2.6. Habitat characteristics

Habitat characteristics of each site were measured at the time of each sample collection. Water quality parameters measured in situ included conductivity and temperature recorded with a Eutech ECTestr pocket sized tester with automatic temperature compensation. Width, depth, and current velocity (with a Marsh McBirney flowmate 2000) were measured in the thalweg at five locations equally spaced along each study reach. Substrate composition was visually assessed and categorised into the groups listed in Table 2. Embeddedness was subjectively assessed as loose, moderate, or tight. Flow type and other habitat variables (e.g., undercutting) were visually assessed for each of the study reaches.

**Table 2:** Substrate size classes used to assess stream and river substrate composition (Quinn & Hickey, 1990).

| | |
|---|---|
| Bedrock | |
| Boulders | > 300 mm |
| Large cobbles | 129-300 mm |
| Small cobbles | 65-128 mm |
| Pebbles | 17-64 mm |
| Gravel | 8-16 mm |
| Sand and silt | < 8 mm |

## 2.7. Biotic indices

Biological indices can be calculated to assess relationships between macroinvertebrate communities and water quality at a study site.

The Macroinvertebrate Community Index (**MCI**) (Stark, 1985) considers the presence of macroinvertebrates based on an assigned score which is dependent on their tolerance to pollution (1= highly tolerant, 10 = highly sensitive).

The Quantitative Macroinvertebrate Community Index (**QMCI**) is similar to the MCI, but also takes into account the number of individuals of each species collected.

Ephemeroptera, Plecoptera and Trichoptera (mayflies, stoneflies and caddisflies) (EPT) consist of insects which are generally sensitive to pollution. The percentage of **EPT taxa** is the proportion of all taxa collected that belong to one of these groups.

The percentage of **EPT individuals** measures the proportion of the individual macroinvertebrates collected that are mayflies, stoneflies and caddisflies.

Values for the biotic indices discussed above indicative of various water quality categories are given in Table 3.

**Table 3:** Interpretation of MCI and QMCI values after Stark & Maxted (2007) for stony streams.

| Interpretation | MCI | QMCI |
|---|---|---|
| Clean water | > 120 | > 6 |
| Mild pollution | 100 -119 | 5 – 6 |
| Moderate pollution | 80 - 99 | 4 – 4.9 |
| Severe pollution | <80 | < 4 |

Differences in biotic indices between sites were assessed using two way analysis of variance (ANOVA) with both treatments considered fixed effects in Statistix 9. Differences in abundance of the invertebrate taxa were assessed using Non Metric Multidimensional Scaling and PERMANOVA in Primer 6.1.13 and PERMANOVA+. Invertebrate densities were log (x+1) transformed prior to analysis. Distances were calculated with the Bray-Curtis distance measure. Significance at $P < 0.05$ indicates a statistically significant change.

# 3. Waingawa River

## 3.1. Background

The Waingawa River originates in the Tararua Ranges and flows for approximately 48 km in a south-easterly direction to its confluence with the Ruamahanga River. It passes through a mixture of native and exotic forest areas, farmland and urban areas, namely the western suburbs of Masterton.

GWRC undertook river management works in the Waingawa River downstream of SH2, between GWRC river monitoring cross sections 4 and 5. (Figures 2-3). The works included approximately 300 m of bed recontouring, coupled with some beach disturbance. Prior to works being undertaken the river alignment posed significant erosion risk on the true left bank near cross section 4+150m to 4+300m. Typical flood protection works involve a sequence of implementation with the overall aim to manage design channel width and to enhance vegetated willow buffers on the left and right of the design channel.

In this case these works were phase one of the intended outcome, phase one being to correct the channel alignment. During the alignment correction work a backwater was created. This backwater was observed by Flood Protection staff to be connected to the main river flow months after the work was completed. However, during summer low flows in March/April 2013 the gravel position had shifted and the backwater was only connected by upstream seepage. The area of backwater does provide potential fish habitat (even if there is no direct connection), although assessing whether fish used it was beyond the scope of our study.

Works were completed on November 13-15, 2012.

Once the alignment issues were remedied, this provided some space for the willow buffer to be established in the area that was previously threatened to erode. GWRC's long term objective of the work is to install willow buffer in the area encircled in green in Plate 1. This may require years of minor channel adjustments (likely less extensive than the initial work observed with this study); and willow planting.

Examples of the sampling locations and works undertaken are shown in Plates 2-6.


**Figure 2:** Map of Waingawa River showing general area where river works were undertaken by GWRC (indicated by red arrow).

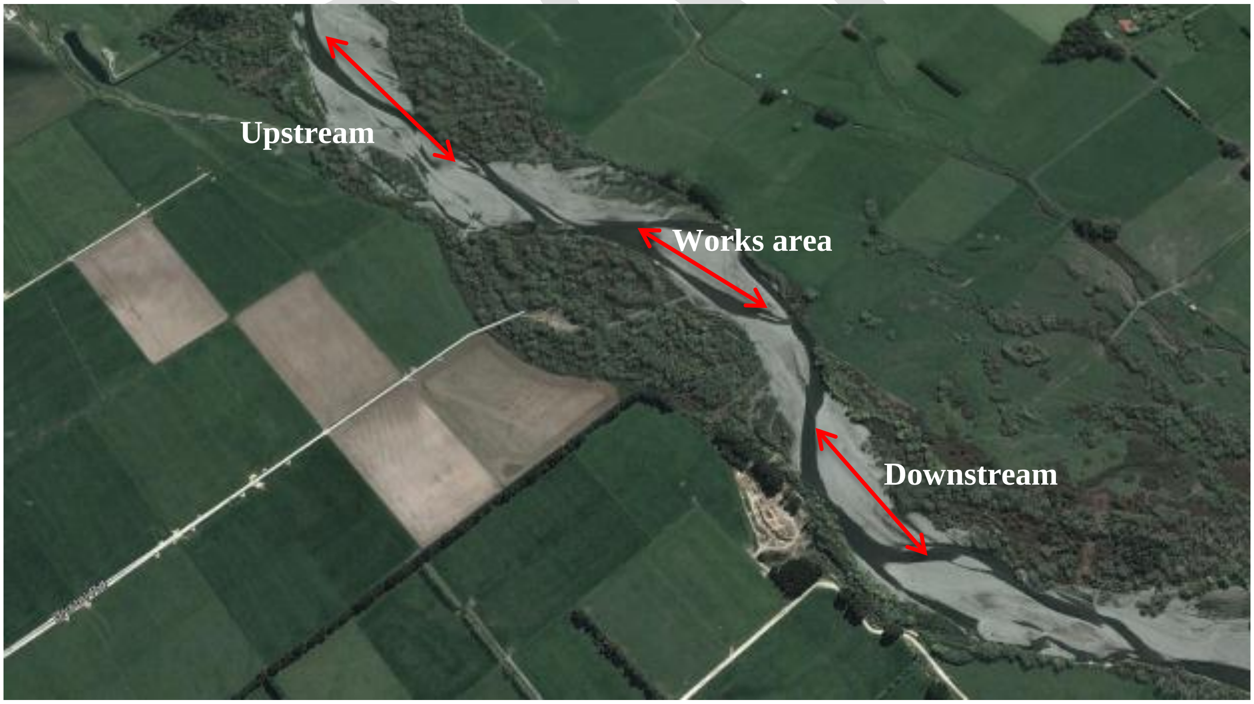



**Figure 3:** Map showing sites sampled on the Waingawa River in 2012.

**Plate 1:** Aerial photograph of the Waingawa River taken on 13 May 2013, six months post-work.

**Plate 2**: Waingawa River upstream of river works area after works undertaken**.**

**Plate 3:** Waingawa River at river works area before works undertaken**.**

**Plate 4:** Waingawa River at river works area following the channel realignment**.**

**Plate 5:** Waingawa River downstream of river works area before works undertaken**.**

**Plate 6:** Area of backwater in Waingawa River upstream from river works during river works.

## 3.2. Data Analysis

### *3.2.1. Habitat characteristics*

The habitat characteristics recorded at each of the sites on the Waingawa River are presented in Table 4 and a hydrograph for the study period is presented in Figure 4.

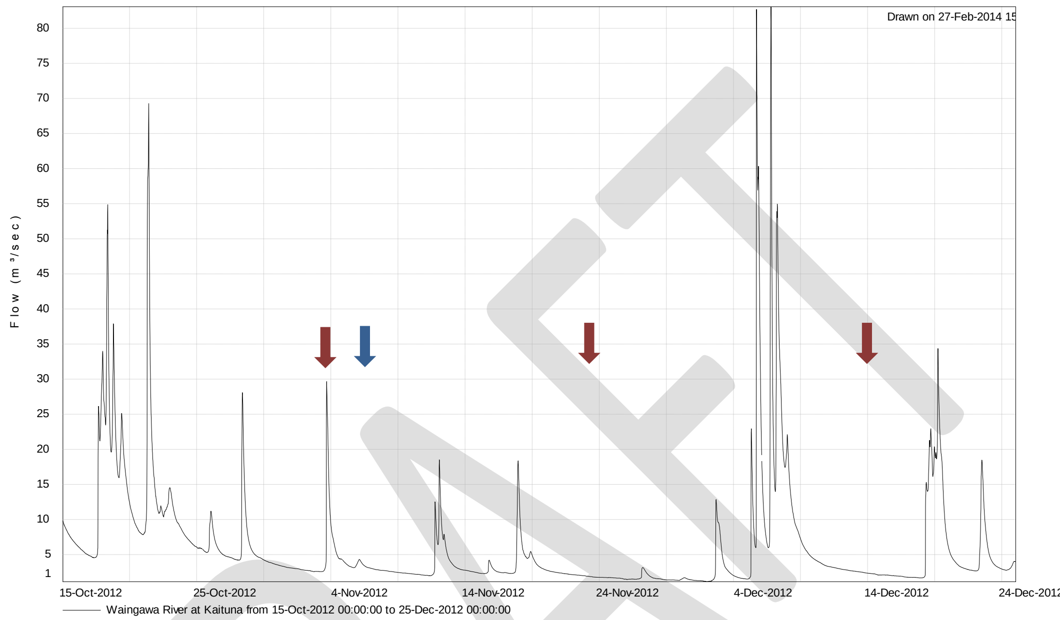



**Figure 4:** Hydrograph of Waingawa River recorded at Kaituna for the period of engineering (blue arrow) and sampling (red arrow).



The upstream site was characterised by riffle areas containing mostly small cobbles and gravel, approximately 30 cm deep, 12-13 m wide, with conductivity ranging from 56 to 62 µS/cm and flow between 0.5 and 1 m/s.

The site where river works were carried out was slightly wider (15 m) and deeper (44 cm), with similar conductivity and flow to the upstream site but substrate here consisted of mostly large cobbles with some smaller cobbles and gravel. Post works the site characteristics changed mainly in relation to substrate composition, substrates now consisting of mostly smaller cobbles, pebbles and gravel, and riffle areas changed to a mixture of riffle and run more similar to the upstream site. The undercut habitat, overgrown with willows, disappeared when the channel was moved and represents a loss of potential fish habitat.

The site downstream of the works was similar to the upstream site although this stretch was a mixture of riffle and run with slightly slower flow (0.3 – 0.7 m/s) and remained relatively unchanged after the engineering works. Flow direction did change slightly because of a redirected flow with a loss of a small amount of undercut habitat.

**Table 4:** Habitat characteristics of sites sampled near river management works areas on the Waingawa River in 2012.

| | Upstream | | | Works Area | | | Downstream | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre Works | Post Works #1 | Post Works #2 | Pre Works | Post Works #1 | Post Works #2 | Pre Works | Post Works #1 | Post Works #2 |
| Date sampled | 2-Nov-12 | 22-Nov-13 | 13-Dec-12 | 2-Nov-12 | 22-Nov-13 | 13-Dec-12 | 2-Nov-12 | 22-Nov-13 | 13-Dec-12 |
| Easting | 2732422 | 2732417 | 2732426 | 2732767 | 2732730 | 2732784 | 2732831 | 2732862 | 2732931 |
| Northing | 6020236 | 6020237 | 6020238 | 6020145 | 6020087 | 6020040 | 6019986 | 6019936 | 6019912 |
| **Chemical** | | | | | | | | | |
| Conductivity (µS/cm) | 62 | 60 | 56 | 61 | 61 | 64 | 63 | 59 | 63 |
| Temperature (°C) | 20 | 20 | 20 | 19 | 18 | 19 | 19 | 16 | 19 |
| **Physical** | | | | | | | | | |
| Mean Width (m) | 15 | 12 | 13 | 10 | 10 | 9 | 15 | 15 | 12 |
| Mean Depth (cm) | 30 | 30 | 33 | 44 | 34 | 32 | 27 | 25 | 40 |
| Mean Velocity (m/s) | 0.48 | 0.62 | 0.98 | 0.43 | 0.37 | 0.92 | 0.39 | 0.31 | 0.71 |
| **Substrate** | | | | | | | | | |
| Embededness | Loose | Loose | Loose | Loose | Loose | Loose | Loose | Loose | Loose |
| % Boulders (>300 mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| % Large Cobbles (129 - 300 mm) | 15 | 15 | 30 | 50 | 20 | 0 | 40 | 20 | 20 |
| % Small Cobbles (65 - 128 mm) | 30 | 30 | 40 | 25 | 40 | 45 | 20 | 20 | 60 |
| % Pebbles (17 - 64 mm) | 0 | 0 | 20 | 0 | 0 | 50 | 0 | 0 | 10 |
| % Gravel (8 -16 mm) | 55 | 55 | 10 | 25 | 40 | 0 | 50 | 40 | 0 |
| % Sand (< 8 mm) | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 10 | 10 |
| Flow Type / flow present on sample day at Kaituna gauge site | 2.7 $m^3/s$ | 2.2 $m^3/s$ | 2.6 $m^3/s$ | 2.7 $m^3/s$ | 2.2 $m^3/s$ | 2.6 $m^3/s$ | 2.7 $m^3/s$ | 2.2 $m^3/s$ | 2.6 $m^3/s$ |
| % Pool | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| % Run | 0 | 50 | 10 | 0 | 30 | 50 | 50 | 50 | 75 |
| % Riffle | 100 | 50 | 90 | 100 | 70 | 50 | 50 | 50 | 10 |
| %Rapid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Undercutting (%) | 0 | 0 | 0 | 50 | 0 | 0 | 5 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Debris jam (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Overhead cover (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Macrophyte cover (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.2.2. Periphyton

Mean periphyton biomass ranged from 0.2 mg/m$^2$ to 6.9 mg/m$^2$. The upstream and works area sites had similar levels of periphyton prior to any works being undertaken. The highest levels of Chlorophyll *a* were seen downstream prior to any works being undertaken (Figure 5).

Following the channel realignment, periphyton levels decreased in the works area and downstream. At the works area this decline was a result of the new substrates that were now exposed to the river and at the downstream site the decline was because of the increase in deposited sediment.

Periphyton levels were lowest at all sites at the second post works sampling which followed a fresh (two flows a day apart at 80 m$^3$/s). Results suggest that works undertaken to realign the channel had effects similar to those resulting from a natural fresh in the river.

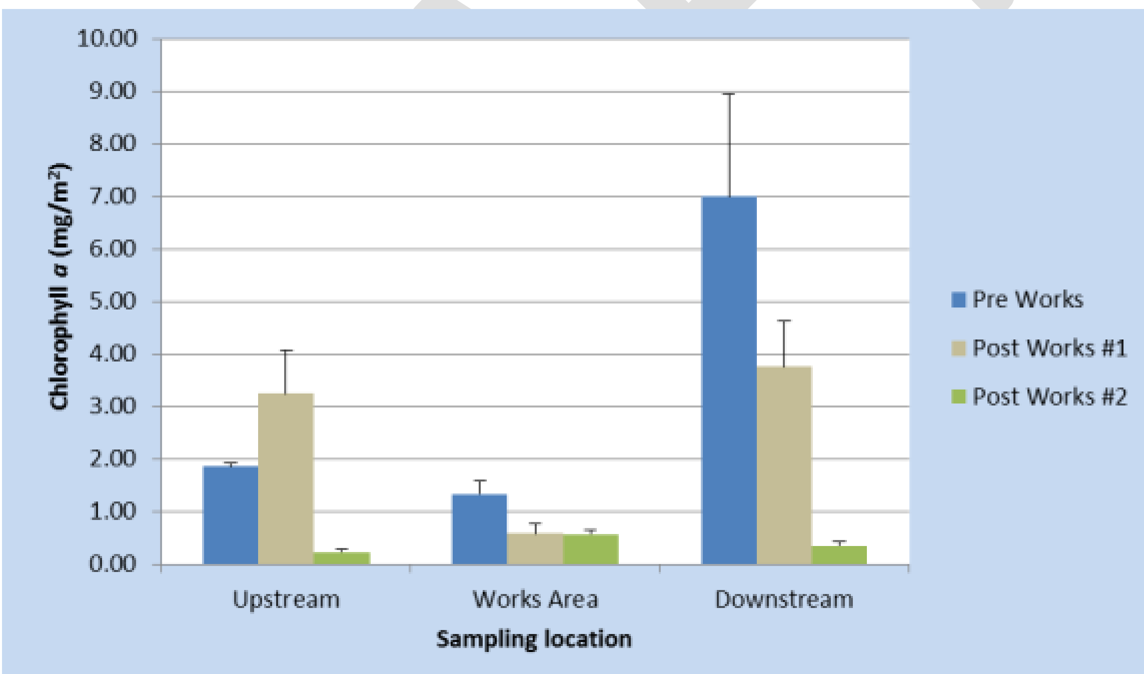



**Figure 5:** Mean periphyton biomass, measured as chlorophyll *a* (mg/m$^2$), for sites sampled on the Waingawa River in 2012.

### *3.2.3. Deposited sediment*

Volumes of deposited sediment were similar at all three sites prior to works being undertaken but increased downstream of the works immediately following channel realignment. Levels of deposited sediment at the downstream site, only a few metres away, were nearly 4 times higher than preworks, but had declined dramatically after a fresh (two flows a day apart at 80 $m^3/s$).

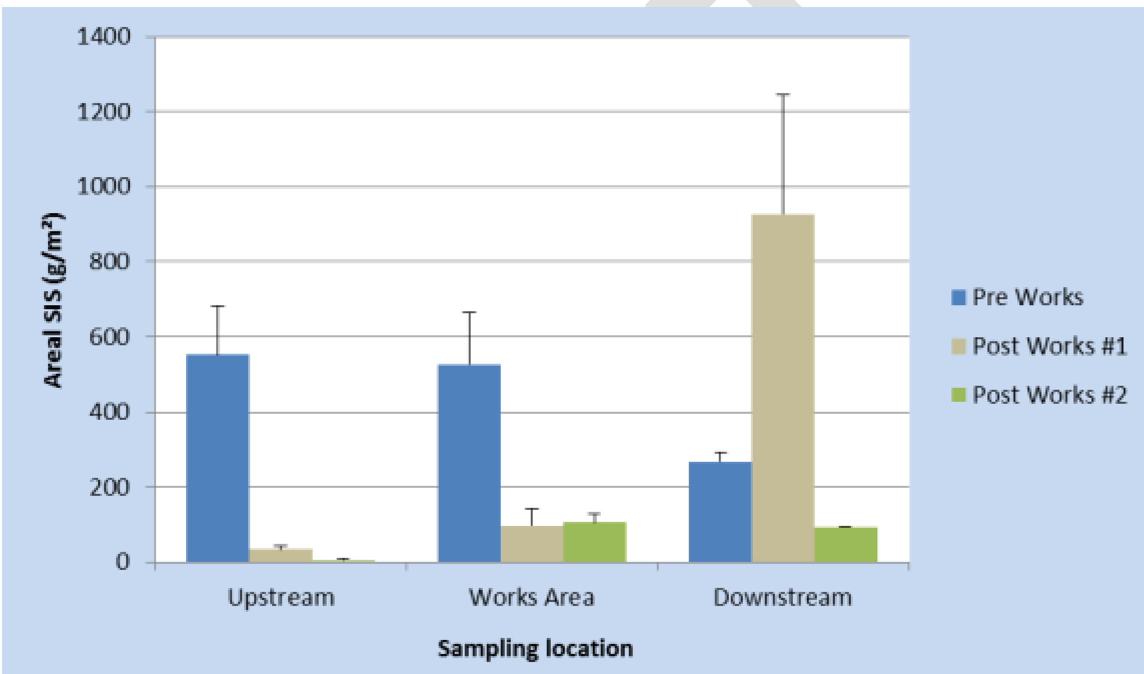



**Figure 6:** Areal deposited inorganic sediment ($g/m^2$) at sites sampled on the Waingawa River in 2012.

### *3.2.4. Macroinvertebrate communities*

Biotic indices for the sites sampled on the Waingawa River are presented in Figures 7-9.

The area where the channel was realigned had the lowest numbers of individuals compared with the upstream and downstream sites both before and after the works.

There was a reduction in the number of individuals and taxa at the works site following the channel realignment. There was also an effect of the works at the downstream site where numbers of individuals, but not taxa, declined post works, probably attributable to increases in deposited sediment and reductions in periphyton biomass. Both indices recovered at the works site but number of individuals had not recovered at the downstream site on the last sampling occasion. The delayed recovery at this site again probably reflects the higher deposited sediment levels post works, which eventually washed away in the first fresh.

The only biological quality index indicating any engineering effect was QMCI which declined immediately post works at the works site and downstream but then recovered again by the second post works sampling three weeks later.

**Table 5:** P values for ANOVA comparing differences in biotic measures between sites and samplings for reaches sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012. Significant values at P<0.05 are indicated in bold. The Site*Sample column is the critical one to identify any works effects over and above differences in site and sample time.

| | Site | Sample | Site * Sample |
|---|---|---|---|
| **Degrees of freedom** | 2,36 | 2,36 | 4,36 |
| **Number of individuals** | **< 0.001** | **0.006** | **< 0.001** |
| **Number of taxa** | **0.002** | 0.57 | **0.003** |
| **% EPT (individuals)** | **0.009** | **0.007** | 0.06 |
| **% EPT (taxa)** | 0.67 | 0.50 | 0.24 |
| **MCI** | 0.17 | 0.08 | 0.53 |
| **QMCI** | **0.005** | **< 0.001** | **0.008** |
| **Chlorophyll *a*** | **< 0.001** | **< 0.001** | **0.002** |
| **Deposited sediment** | 0.07 | **0.002** | **< 0.001** |

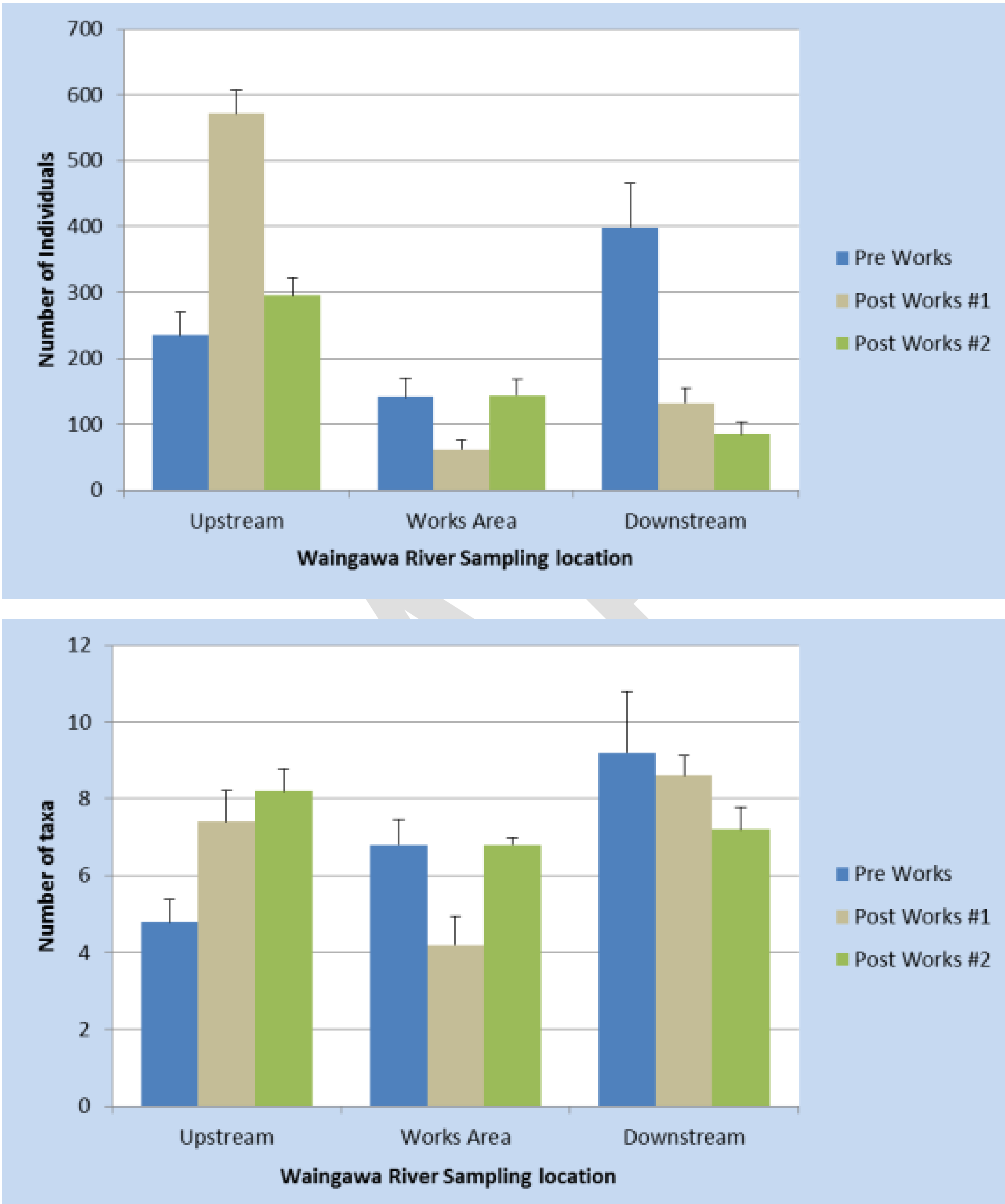
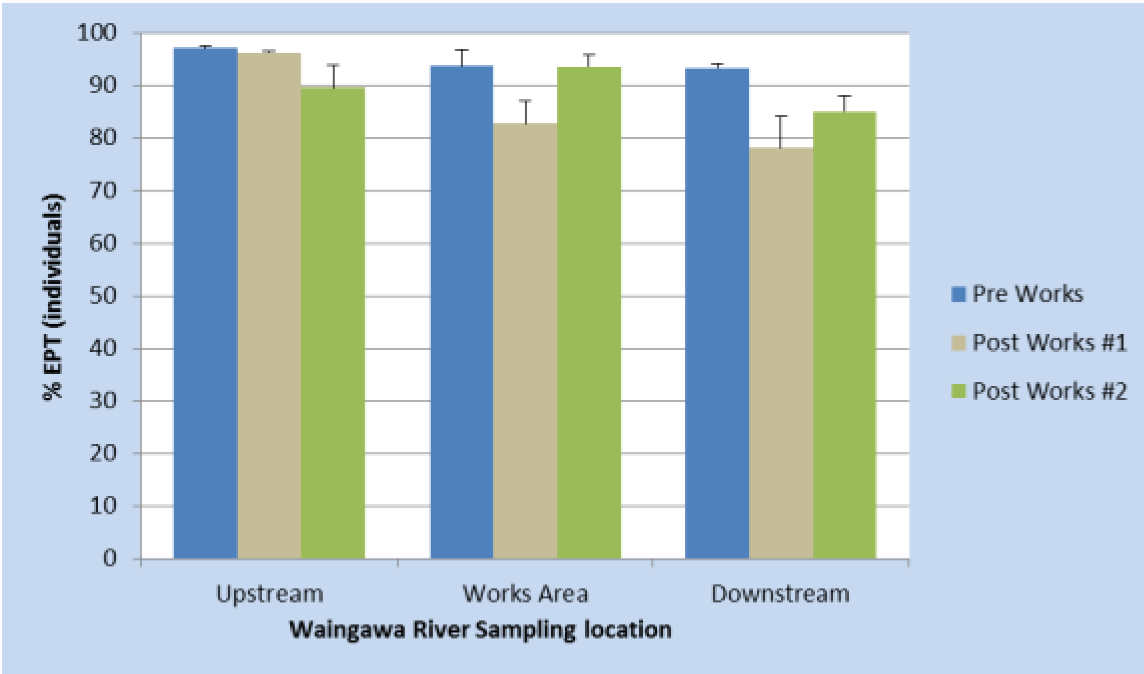



**Figure 7:** Mean (± 1 SE) A. Number of individuals and B. Number of taxa for sites sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012.



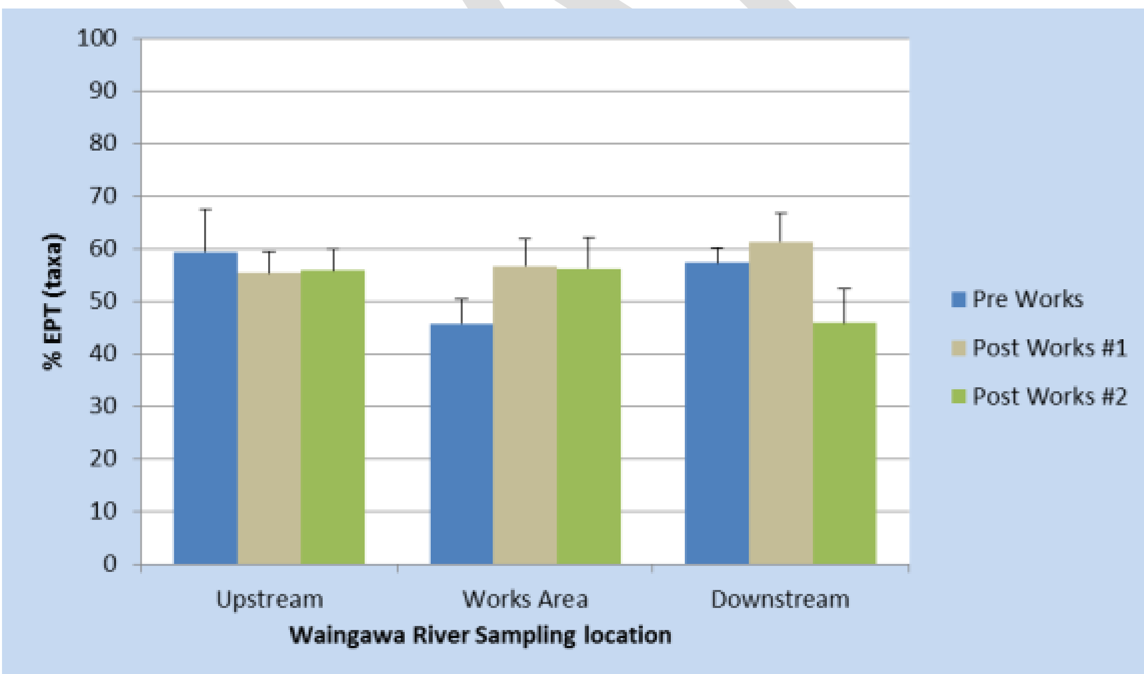




**Figure 8:** Mean (± 1 SE) A. % EPT (individuals) and B. % EPT (taxa) for sites sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012.

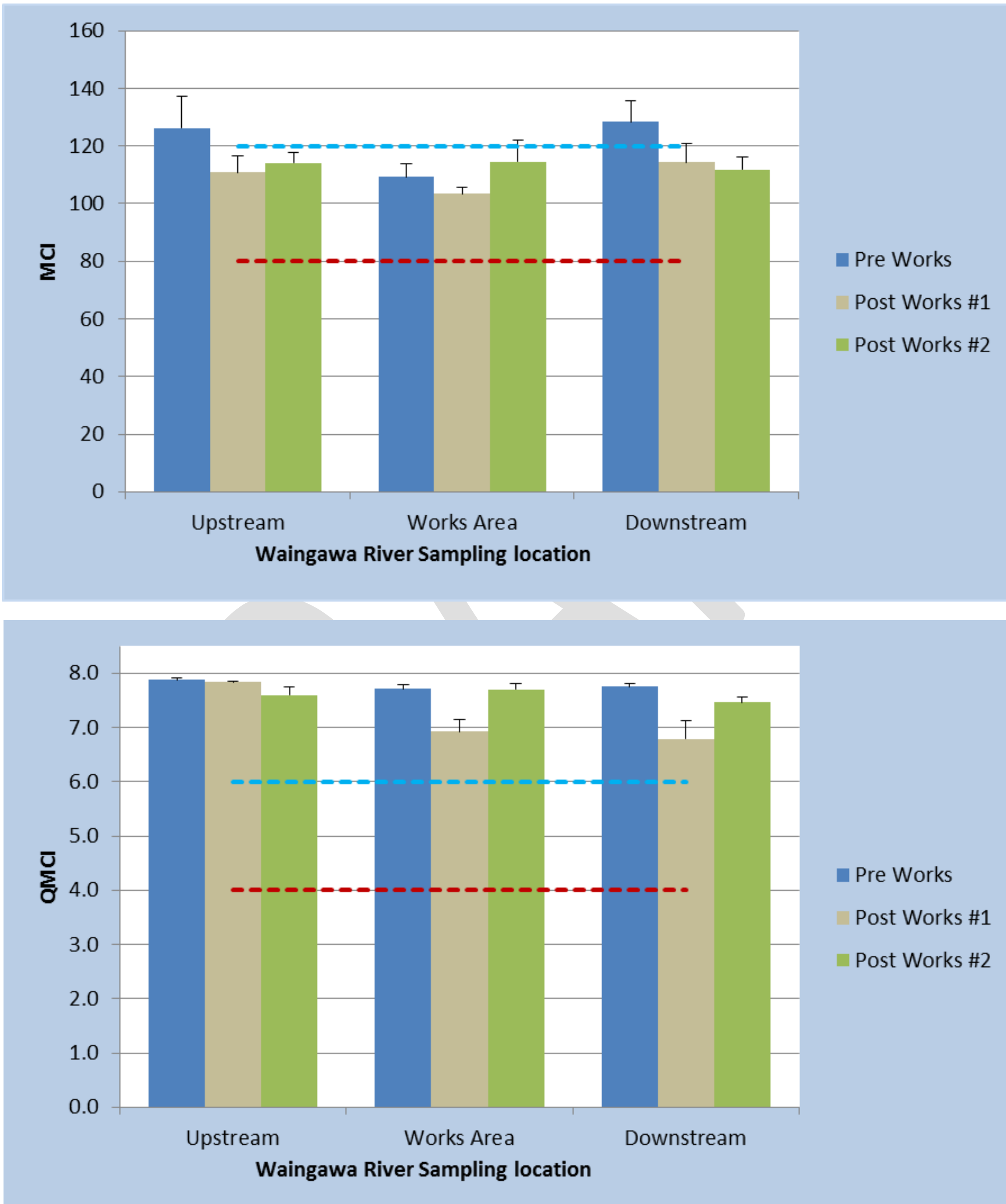



**Figure 9:** Mean (± 1 SE) A. MCI and B. QMCI for sites sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012. Thresholds indicative of good water quality are plotted as a blue dashed line and those of poor water quality as a red dashed line. (Refer Table 3).

The macroinvertebrate taxa collected at each site are presented in Appendix A and the relative abundance of the main groups of macroinvertebrates at these sites is presented in Figure 10. Communities at all sites were dominated by the mayfly *Deleatidium* sp. Immediately following the channel realignment, communities at the works and downstream sites had increased numbers of Chironomidae and other Diptera.

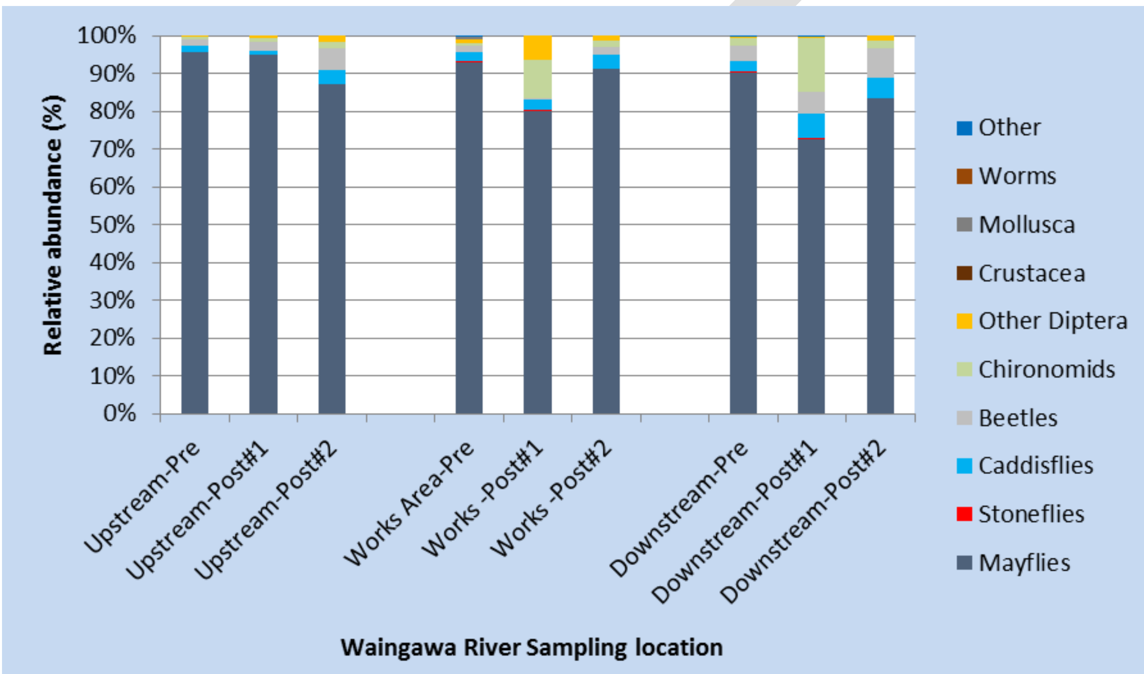



**Figure 10:** Relative abundance of the main taxonomic groups collected at sites sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012.

A plot of axis 1 against axis 2 from a Non Metric Multidimensional Scaling (NMDS) ordination also shows macroinvertebrate communities at all sites regardless of sampling occasion to be similar to each other with the exception of communities at the works site immediately following the river works (circled on Figure 11. These results show that the river works undertaken on the Waingawa River had a short lived effect with communities returning to their pre-works state within a few weeks and after the first fresh.

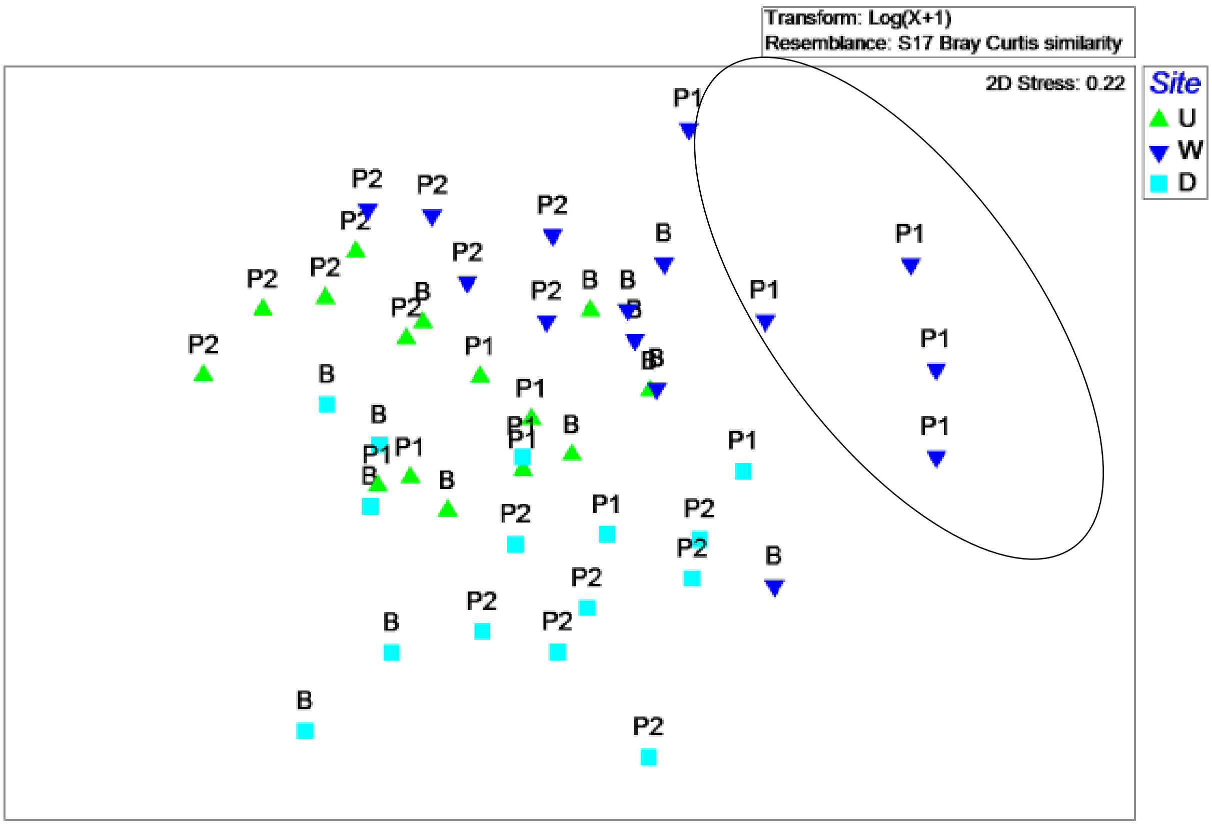



**Figure 11:** Plot of Axis 1 against Axis 2 from a Non Metric Multidimensional Scaling Ordination (Stress = 0.22) for invertebrate communities collected on three sites of the Waingawa River in relation to river works undertaken by GWRC in 2012. U – upstream, W – works and D – downstream site; B – before, P1 – first post-works sampling and P2 – final post-works sampling after a fresh.



### *3.2.5. Fish communities*

The response of fish communities is difficult to generalise as the three sites actually differ from each other quite dramatically in their fish fauna before any engineering works, and furthermore each species also responds quite differently (Figures 12-17). There were no significant differences in the number of species between sites or with the engineering works but there was a big difference in the number of fish with time of sampling, although this appeared unrelated to the engineering work (Table 6).

Bullies (*Gobiomorphus* sp.) declined in abundance over time irrespective of any engineering effects. Both the Works and Downstream sites had more Bullies than the Upstream site. The engineering works appear to result in a slight decline in abundance (but this is not statistically significant), over and above that seasonal change, but numbers have recovered by the last sampling.

In contrast eels and torrentfish (*Cheimarrichthys fosteri*) were more abundant at the Upstream site, eel numbers increased at the engineered site on only one sampling post works but were rare or absent at the Downstream site. Torrentfish were rare or absent at the works and Downstream sites.

Trout were more abundant at the Downstream site than at the other two sites, but seemed to decline in abundance at the Downstream site post-works probably because of the increase in deposited sediment and decline in numbers of invertebrates. They are the only fish species that shows any clear effect of the engineering works, and this was at the downstream site not the actual works site.

Drawing these results together it would seem Bullies are temporally affected by the river works but recover after the first fresh, eels may increase, trout decrease and torrentfish are unaffected. However, interpretation of these results must be tempered by the fact that there are large between site differences in fish faunas. For example, there were few, if any, torrentfish at the Works or Downstream sites so it is impossible to know if they would be adversely affected; all that can be concluded is that habitat was not enhanced for them.

**Table 6:** P values for ANOVA comparing differences in fish (at the genus level) between sites and samplings for reaches sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012. Significant values at $P<0.05$ are indicated in bold. The Site*Sample column is the critical one to identify any works effects over and above differences in site and sample time.

| | Site | Sample | Site * Sample |
|---|---|---|---|
| **Degrees of freedom** | *2,17* | *2,17* | *4,17* |
| **Number of fish** | 0.72 | **0.02** | 0.60 |
| **Number of taxa** | 0.36 | 0.56 | 0.66 |
| **Bullies** | 0.09 | **0.002** | 0.48 |
| **Eels** | **0.03** | 0.20 | 0.05 |
| **Torrentfish** | **0.002** | 0.30 | 0.51 |
| **Trout** | **0.03** | **0.01** | **0.02** |

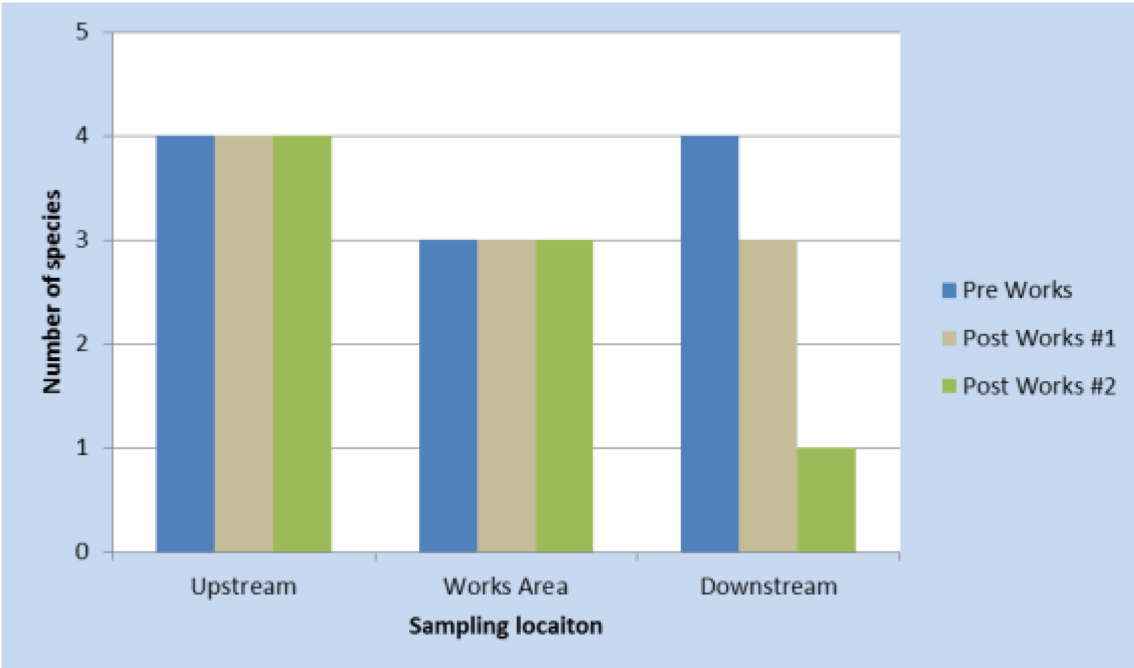



**Figure 12:** Number of species collected on each sampling occasion in the Waingawa River in 2012.

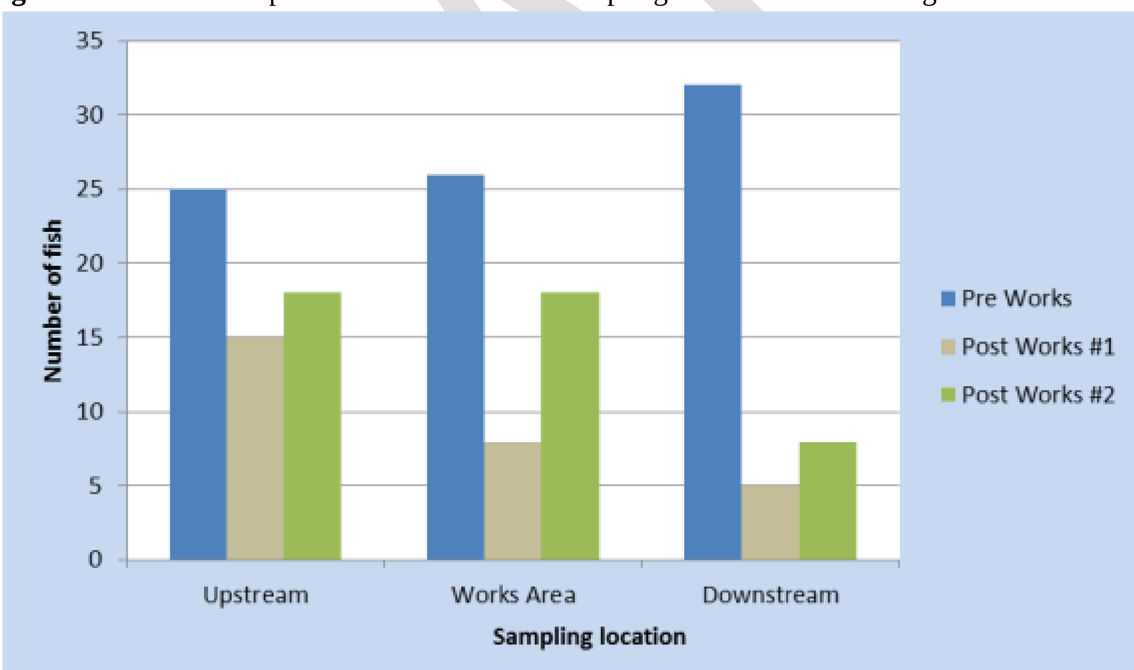



**Figure 13:** Number of fish collected on each sampling occasion in the Waingawa River in 2012.

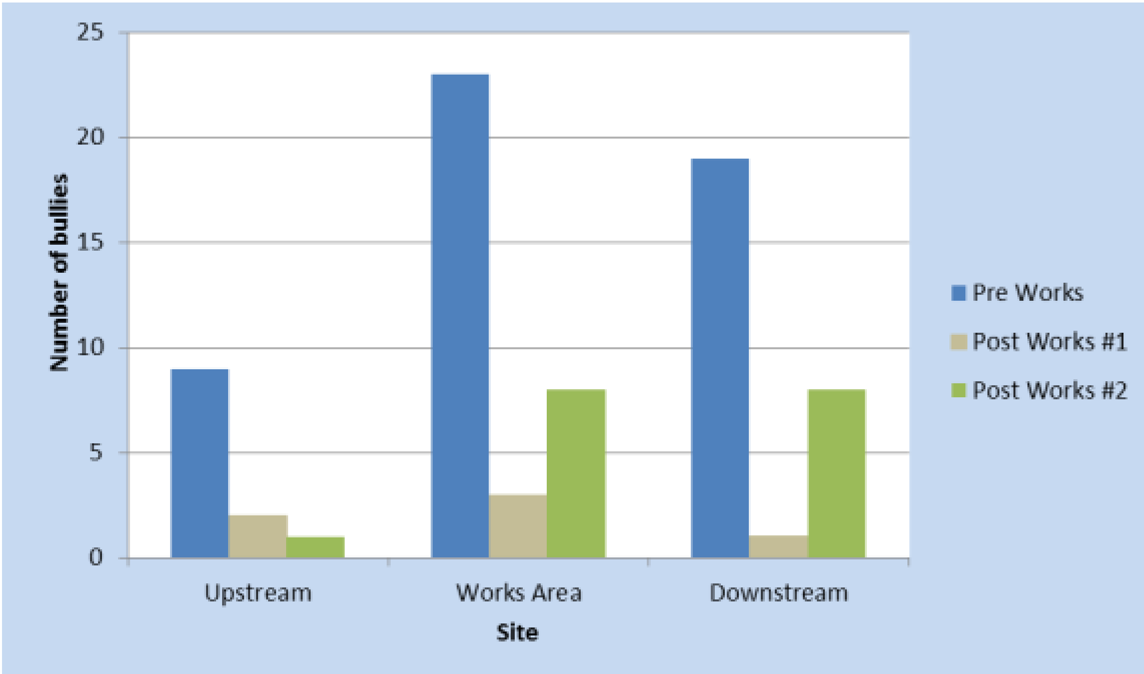



**Figure 14:** Numbers of bullies (*Gobiomorphus* sp.) present at each site sampled on the Waingawa River in 2012.

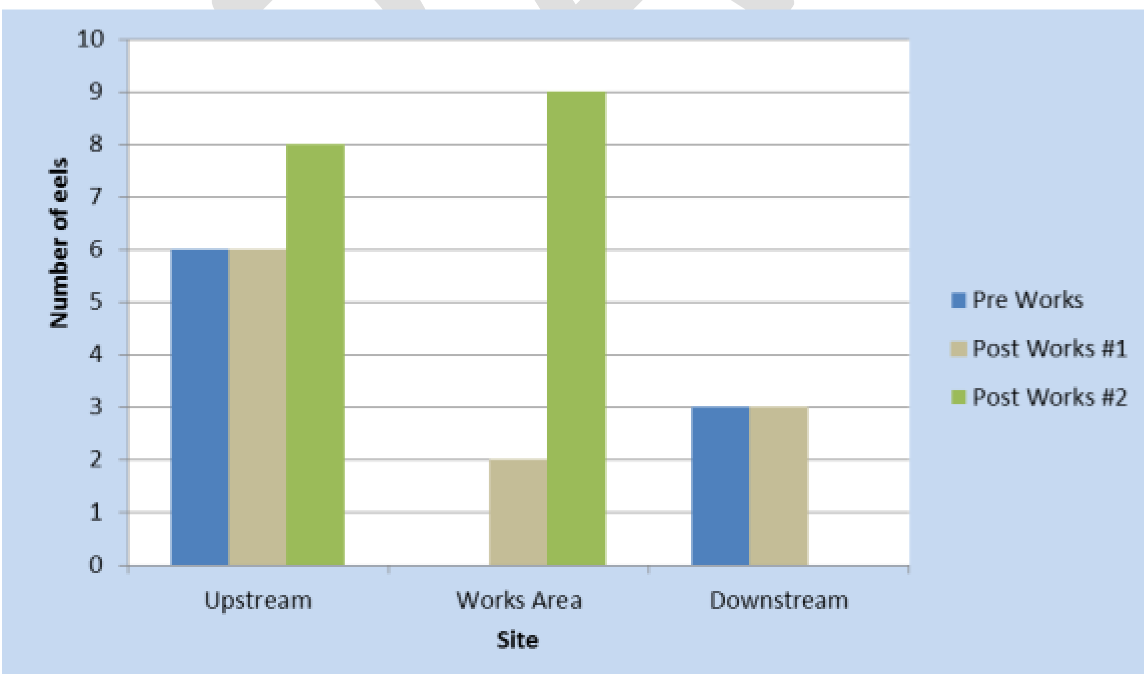



**Figure 15:** Numbers of eels (*Anguilla* sp.) present at each site sampled on the Waingawa River in 2012.

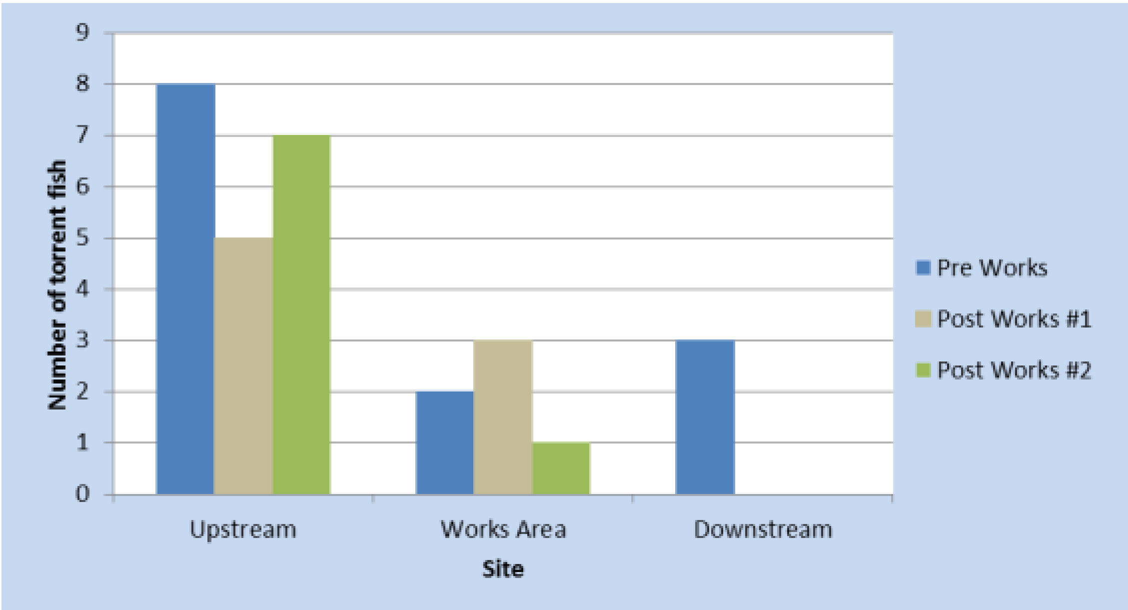



**Figure 16:** Numbers of torrentfish (*Cheimarrichthys fosteri*) present at each site sampled on the Waingawa River in 2012.

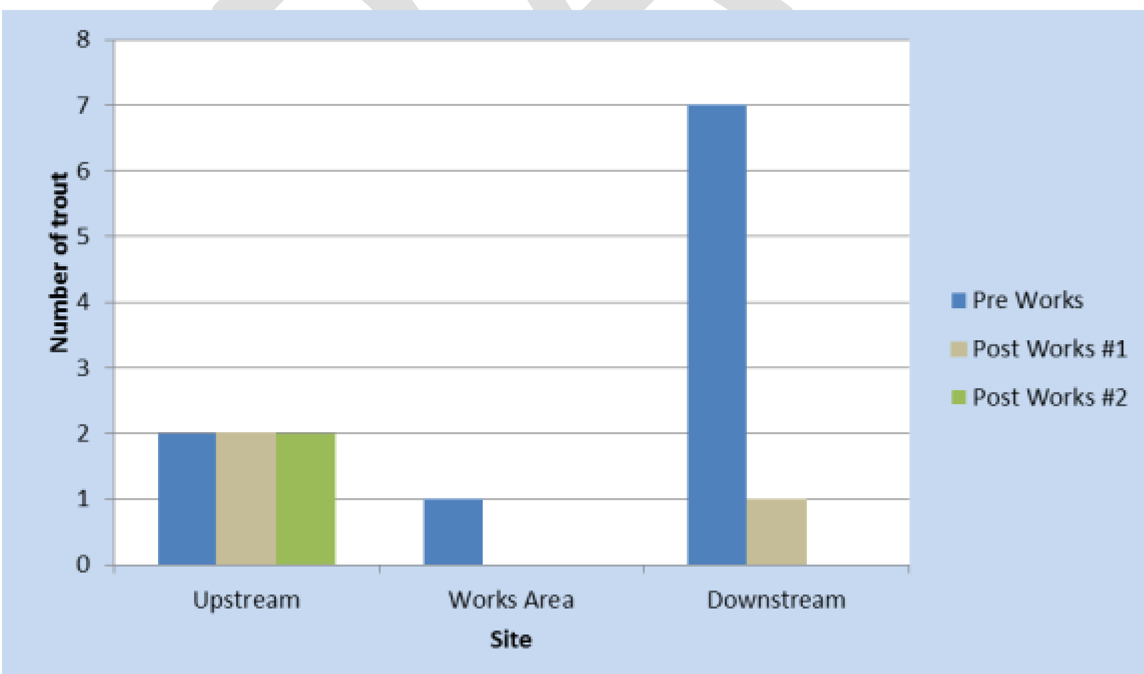



**Figure 17:** Numbers of trout (*Salmo* sp.) present at each site sampled on the Waingawa River in 2012.

### 3.3. Summary of Findings

River works carried out in a stretch of the Waingawa River in 2012 included 100-150 m of channel realignment and cross blading, coupled with some beach disturbance. An area of backwater with a small connection to the main stem of the river was retained by the works that potentially offers good fish habitat, but this was not specifically assessed by our study.

Moving the river channel away from the undercut eroding bank did change the habitat in the engineered reach and immediately downstream. The substrate was reduced in size, flows were more channelized and overhanging banks and vegetation removed from direct association with the flowing water. This resulted in the loss of periphyton and increases in deposited sediment at the downstream site, but levels of both after the first fresh could not be differentiated from the upstream site that was not affected by the engineering works.

Numbers of macroinvertebrates and species declined, and macroinvertebrate community composition changed at the works site immediately after the works, but recovered after the first fresh (two flows at 80 $m^3/s$ a day apart) five weeks later. The QMCI was the only biological quality index affected by the works, which declined at the downstream and works sites immediately post-works, but recovered after the first fresh. The number of macroinvertebrates was the only biological characteristic that had not recovered to pre-works level following the sampling after the fresh. This is likely to be the result of a combination of increased deposited sediment levels from the engineering, reduced periphyton biomass from the engineering and fresh, and the direct effects of the fresh.

Comparison of the effects of the engineering works on fish communities was difficult to assess because there were differences in fish assemblages between the sites before the engineering works. However, it seems of the fish present in reasonable numbers at the engineered or downstream sites, trout were the only species detrimentally affected; eel in fact seemed to increase in number at least during the length of this study. Trout numbers were affected only at the downstream site (they were not abundant at the other sites) most likely from declines in macroinvertebrate numbers and increases in deposited sediment. Changes in habitat structure and quality that occurred in the works site did not occur at the downstream reach so cannot explain the trout response.

Most of the biological and deposited sediment effects that occurred directly after the channel realignment in the Waingawa River were similar to those at the upstream site following the first fresh. The number of macroinvertebrates and trout, that appeared to be responding to the deposited sediment increases at the downstream site, were the only parameters that were still low at the final sampling.

# 4. Waiohine River

## 4.1. Background

The Waiohine River flows from the Tararua Ranges for about 20 km to its confluence with the Ruamahanga River northeast of Greytown, covering a catchment area of 378 sq km.

River management works undertaken in the Waiohine River upstream of SH2 (Figure 18-19) included the installation of rock groynes and bed recontouring. In total, about 80 metres of channel disturbance was involved with the work undertaken at this site. The work was carried out on 22 September 2012 at GWRC cross section 25+45m to 25+120m on the true left bank.

The Waiohine River Scheme utilises different management methods to the Waingawa River Scheme. The main difference being the use of heavy rock (rough diameter 600mm-1200mm) to construct erosion protection structures, referred to as groynes. This work was required due to the erosion threat on the true left bank which was in close proximity to a scheme maintained stopbank.

At the time of producing the final draft of this report the rock groynes had required only minor maintenance which consisted of using a digger to re-stack some boulders in February 2014. GWRC considers this to be minimal maintenance in consideration of the sequence of flood events that persisted from September 2013 to January 2014.

Examples of the sites sampled on the Waiohine River in 2013 are shown in Plates 7-13.


**Figure 18:** Map of Waingawa River showing general area where river works were undertaken by GWRC (indicated by red arrow).

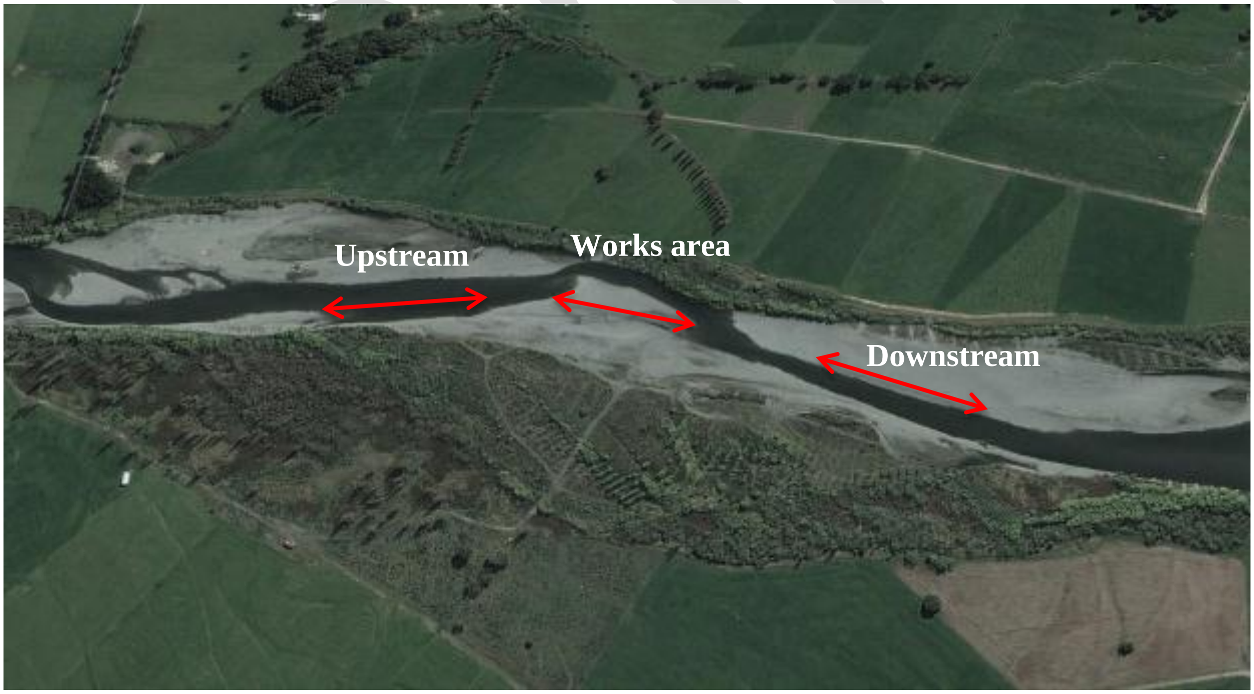



**Figure 19:** Map showing sites sampled on the Waiohine River in 2012.

**Plate 7:** Rock groynes being placed in a stretch of the Waiohine River in 2012.

**Plate 8:** Example of works undertaken in the Wairarapa region in 2012

**Plate 9:** River works being undertaken in a stretch of the Waiohine River in 2012.

**Plate 10:** Waiohine River upstream of river works area before works undertaken**.**

**Plate 11:** Waiohine River at river works area prior to the placement of rock groynes**.**

**Plate 12:** Waiohine River at river works area with rock groynes in place**.**

**Plate 13:** Waiohine River downstream of river works area before works undertaken**.**



## 4.2. Data Analysis

### *4.2.1. Habitat characteristics*

The habitat characteristics recorded at each of the sites on the Waiohine River are presented in Table 7 and a hydrograph for the study period presented in Figure 20.

The upstream and downstream sites were characterised by riffle areas containing mostly large and small cobbles with some gravel. The upstream site was approximately 40 m wide; 26 cm deep with conductivity ranging from 51 to 57 µS/cm and flow between 0.4 and 0.7 m/s. Downstream was slightly narrower and deeper at 38 m wide and 25-38 cm deep.

The reach where river works were undertaken was a run with flows between 0.26 and 0.31 m/s, 40 m wide, 36-38 cm deep and substrate consisting mainly of small cobbles and pebbles prior to works and small cobbles, gravel and sand following the works.

The engineering works had minimal effect on any measured habitat characteristics. The addition of the rock groynes to the engineered reach, within the undercut willow bank would have most likely increased potential fish habitat, but we did not directly assess this as there was no upstream/downstream equivalent for comparison, i.e., it was an addition only to the works site. Macroinvertebrates and fish were sampled on the opposite, shallower river bank to the bank where rock groynes were placed, but was the river edge with the most bulldozer activity (the bulldozer worked from the shallow to deeper edge).

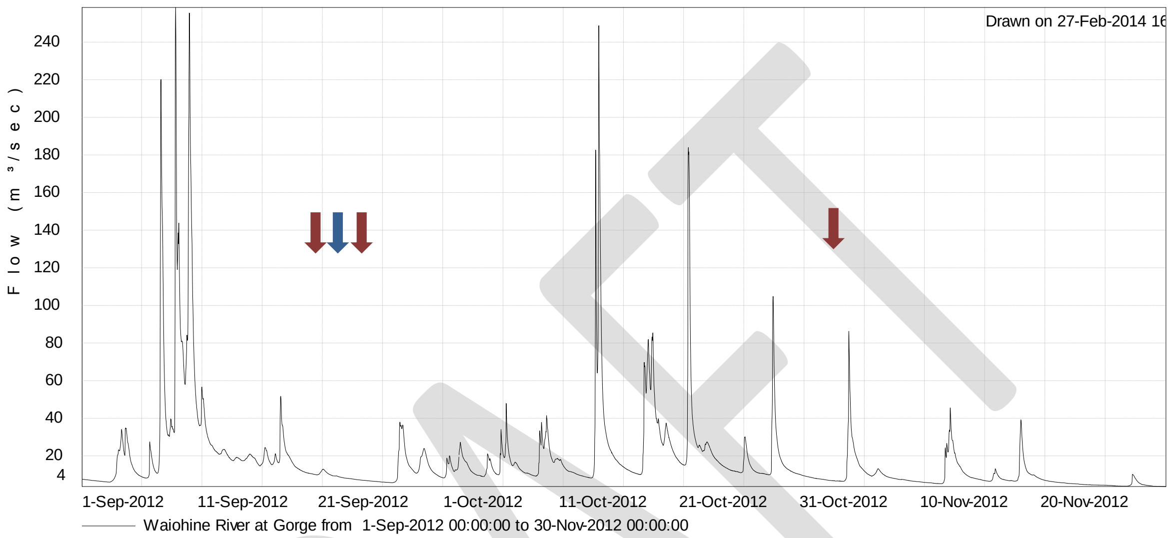



**Figure 20:** Hydrograph of Waiohine River recorded at the Gorge for the period of engineering (blue arrow) and sampling (red arrow).

**Table 7:** Environmental characteristics of sites sampled near river management works areas on the Waiohine River in 2012.

| | Upstream | | | Works Area | | | Downstream | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre Works | Post Works #1 | Post Works #2 | Pre Works | Post Works #1 | Post Works #2 | Pre Works | Post Works #1 | Post Works #2 |
| Date sampled | 17/09/2012 | 21/09/2012 | 1/11/2012 | 17/09/2012 | 21/09/2012 | 1/11/2012 | 17/09/2012 | 21/09/2012 | 1/11/2012 |
| Easting | 2716492 | 2716467 | 2716454 | 2716721 | 2716733 | 2716718 | 2716815 | 2716824 | 2716830 |
| Northing | 6013337 | 6013337 | 6013333 | 6013318 | 6013318 | 6013327 | 6013247 | 6013247 | 6013242 |
| **Chemical** | | | | | | | | | |
| Conductivity (µS/cm) | 51 | 55 | 57 | 48 | 55 | 55 | 46 | 55 | 59 |
| Temperature (°C) | 14 | 14 | 19 | 13 | 15 | 20 | 12 | 13 | 16 |
| **Physical** | | | | | | | | | |
| Mean Width (m) | 40 | 40 | 40 | 40 | 40 | 40 | 38 | 38 | 38 |
| Mean Depth (cm) | 26 | 26 | 23 | 38 | 36 | 36 | 38 | 37 | 25 |
| Mean Velocity (m/s) | 0.71 | 0.49 | 0.37 | 0.31 | 0.26 | 0.31 | 0.75 | 0.59 | 0.45 |
| **Substrate** | | | | | | | | | |
| Embeddedness | Loose | Moderate | Moderate | Loose/ moderate | Loose | Loose | Loose | Loose | Loose |
| % Boulders (>300 mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| % Large Cobbles (129 - 300 mm) | 40 | 40 | 40 | 10 | 5 | 5 | 20 | 30 | 30 |
| % Small Cobbles (65 - 128 mm) | 30 | 40 | 40 | 25 | 40 | 15 | 40 | 45 | 45 |
| % Pebbles (17 - 64 mm) | 30 | 0 | 0 | 45 | 0 | 0 | 0 | 12.5 | 12.5 |
| % Gravel (8 -16 mm) | 0 | 20 | 20 | 0 | 50 | 10 | 40 | 12.5 | 12.5 |
| % Sand (< 8 mm) | 0 | 0 | 0 | 20 | 5 | 70 | 0 | 0 | 0 |
| **Flow Type / flow present on sample day at gorge** | 16.0 $m^3/s$ | 10 $m^3/s$ | 7.5 $m^3/s$ | 16.0 $m^3/s$ | 10 $m^3/s$ | 7.5 $m^3/s$ | 16.0 $m^3/s$ | 10 $m^3/s$ | 7.5 $m^3/s$ |
| % Pool | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| % Run | 0 | 0 | 0 | 80 | 100 | 100 | 0 | 0 | 0 |
| % Riffle | 100 | 100 | 100 | 20 | 0 | 0 | 100 | 100 | 100 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| %Rapid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Undercutting | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Debris jam | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Overhead cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Macrophyte cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 4.2.2. *Periphyton*

Mean periphyton biomass ranged from 0.2 mg/m$^2$ to 19.3 mg/m$^2$.

Upstream and downstream sites followed similar patterns with increasing levels of periphyton over time (Figure 21).

Periphyton biomass at the works site was generally lower overall samplings compared with upstream and downstream, but decreased immediately following the river engineering.

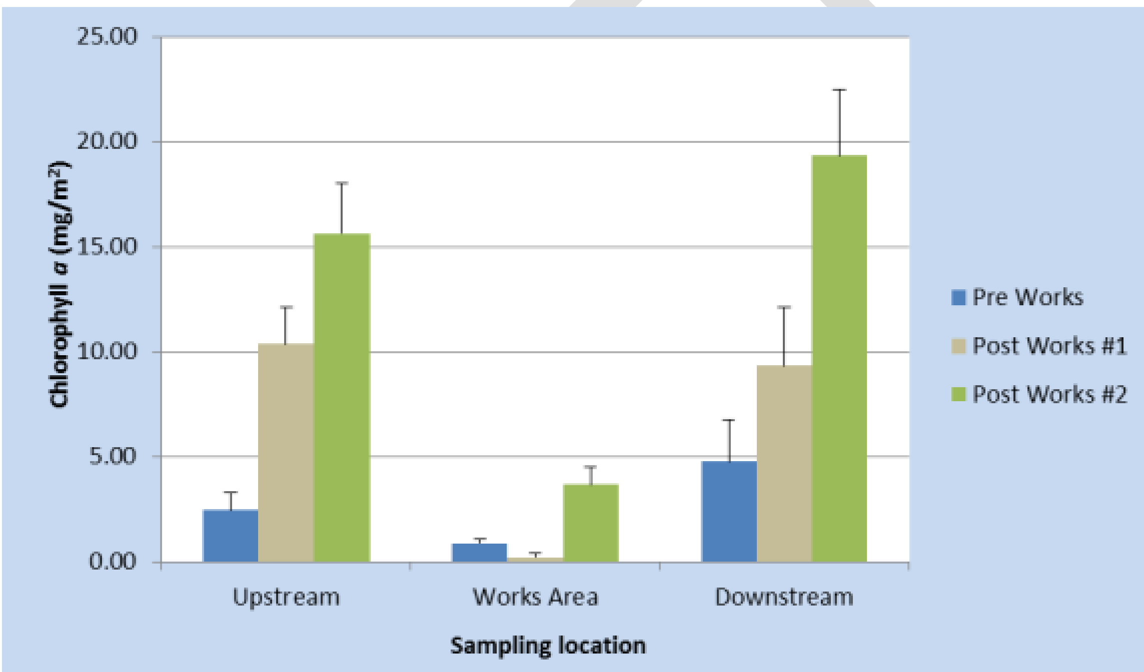



**Figure 21:** Mean periphyton biomass, measured as chlorophyll *a* (mg/m$^2$), for sites sampled on the Waiohine River in 2012.

# 4.2.3. Deposited sediment

Volumes of deposited sediment increased at all three sites on the second collection (Figure 22). As increases also occurred at the upstream site, not all the changes in deposited sediment levels here are a result of the river engineering at this site, but some is likely to have been. Sediment levels did decrease again at all three sites after the fresh event.

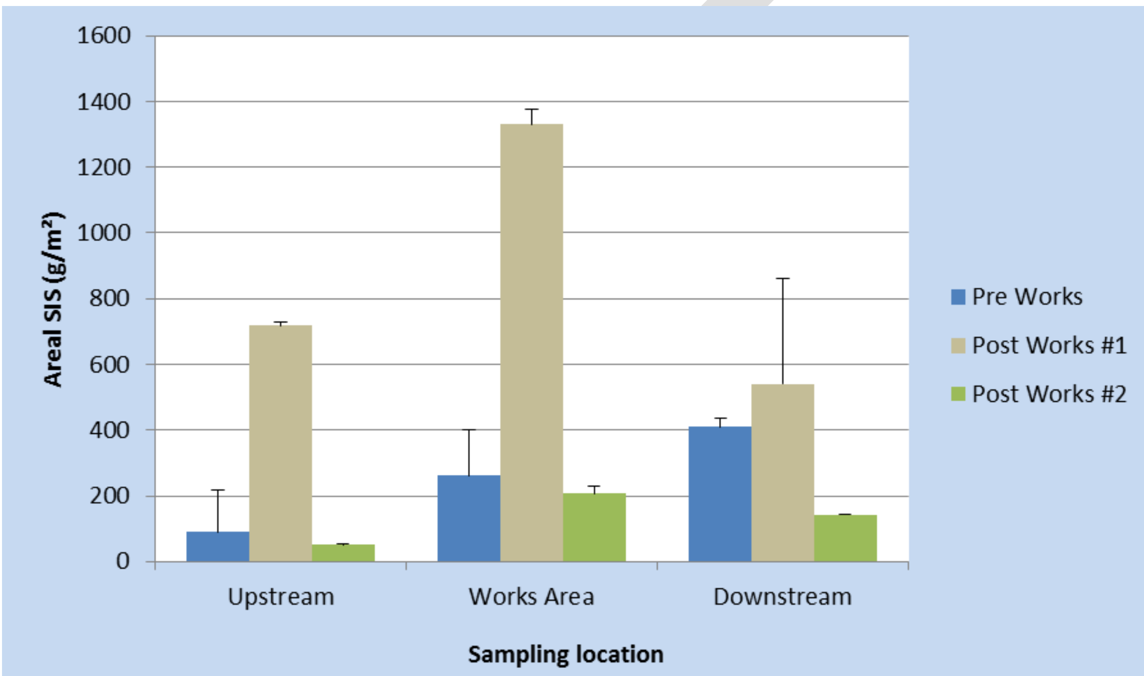



**Figure 22:** Areal deposited inorganic sediment (g/m$^2$) at sites sampled on the Waiohine River in 2012.

### *4.2.4. Macroinvertebrate communities*

Biotic indices for the sites sampled on the Waiohine River are presented in Figures 23-25.

There were significant differences in number of individuals and number of taxa between sites and samplings. Numbers of individuals and taxa at the works site decreased to 1/5 and half of that pre-works, respectively, immediately following the works, but did not change at the downstream reach. These variables returned to pre-works levels by the time of the second post-works sampling 20 days after a 250 $m^3$/s flood.

There was an effect of the works on % EPT individuals but the reduction was very small, and of the three sites, the work site had the highest % EPT individuals. There were no significant differences between sites, samplings or the effect of the works for %EPT taxa, MCI or QMCI.

**Table 8:** P values for ANOVA comparing differences in biotic indices between sites and samplings for reaches sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012. Significant values at P<0.05 are indicated in bold. The Site*Sample column is the critical one to identify any works effects over and above differences in site and sample time.

| | Site | Sample | Site * Sample |
|---|---|---|---|
| **Degrees of freedom** | 2,35 | 2,35 | 4,35 |
| **Number of individuals** | **< 0.001** | **< 0.001** | **< 0.001** |
| **Number of taxa** | **< 0.001** | **< 0.001** | **< 0.001** |
| **% EPT (individuals)** | **< 0.001** | 0.10 | **0.04** |
| **% EPT (taxa)** | 0.26 | 0.56 | 0.55 |
| **MCI** | 0.67 | 0.52 | 0.38 |
| **QMCI** | 0.06 | 0.50 | 0.32 |
| **Chlorophyll *a*** | **< 0.001** | **< 0.001** | **0.02** |
| **Deposited sediment** | **0.04** | **< 0.001** | 0.05 |

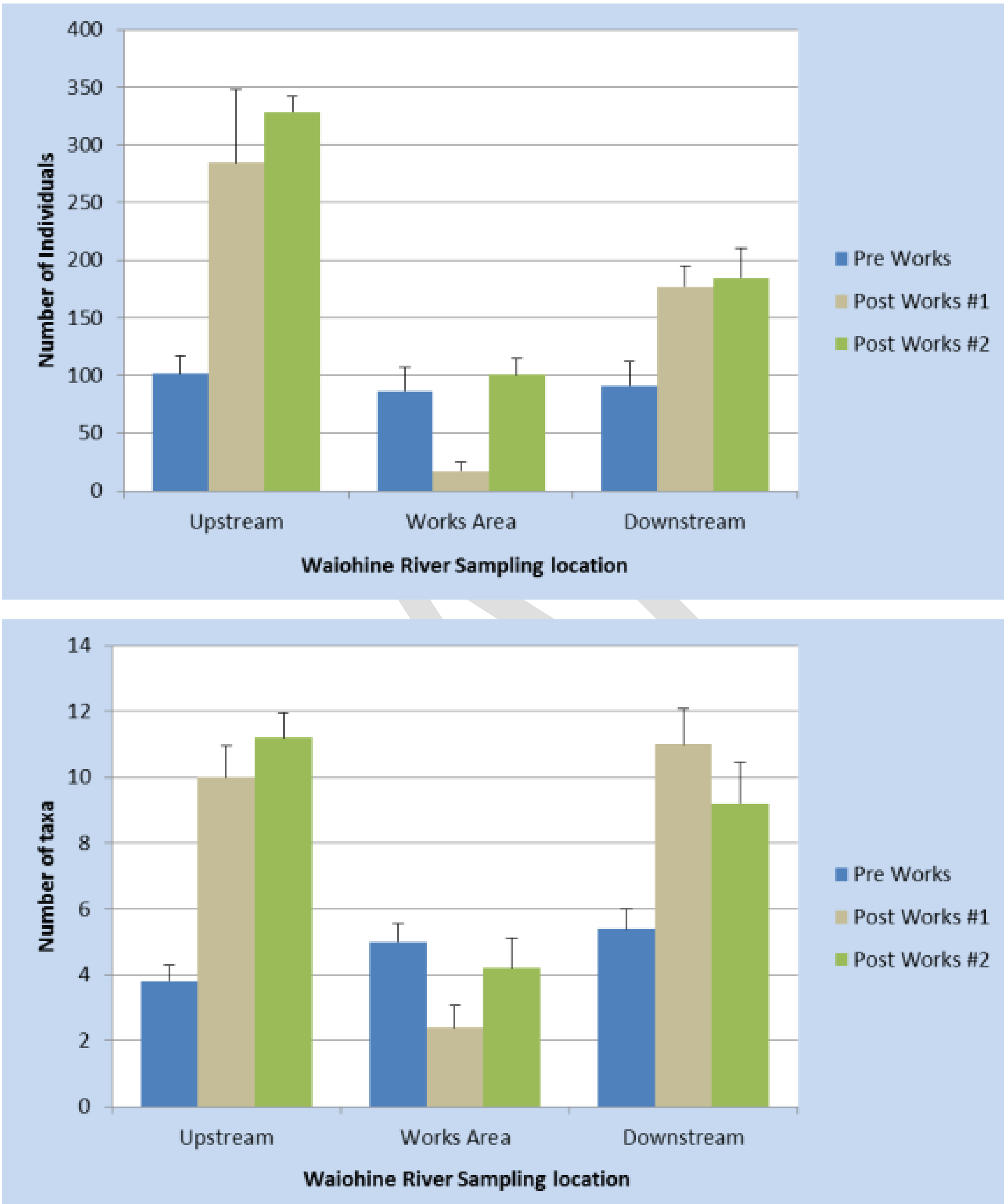
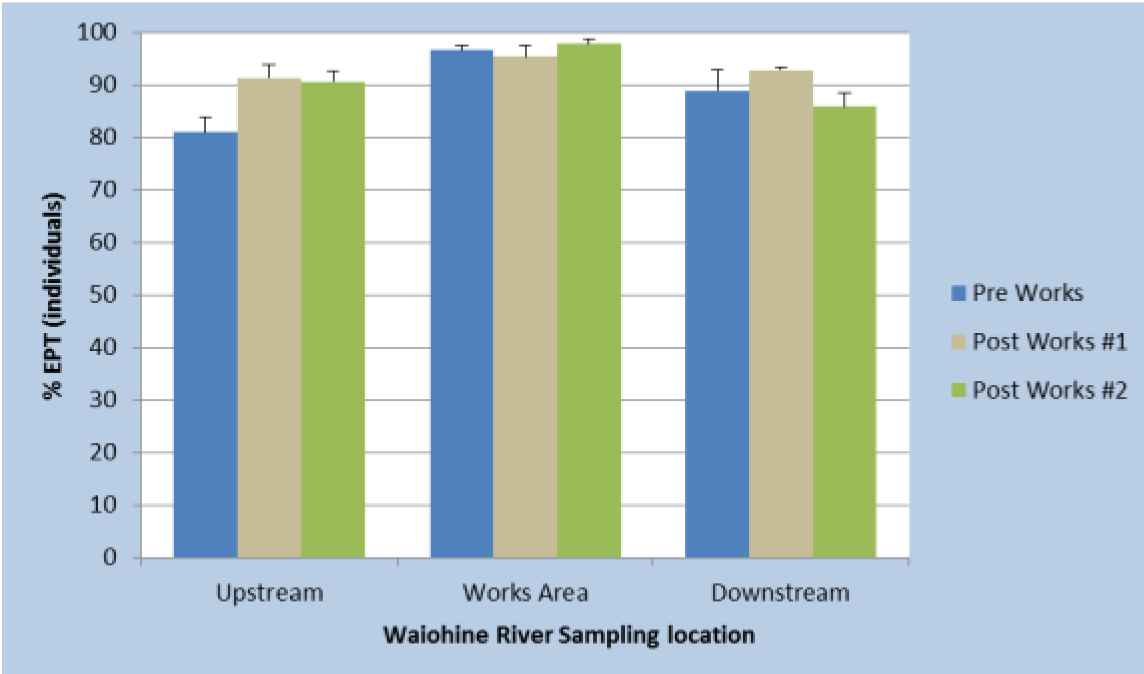



**Figure 23:** Mean (± 1 SE) A. Number of individuals and B. Number of taxa for sites sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012.



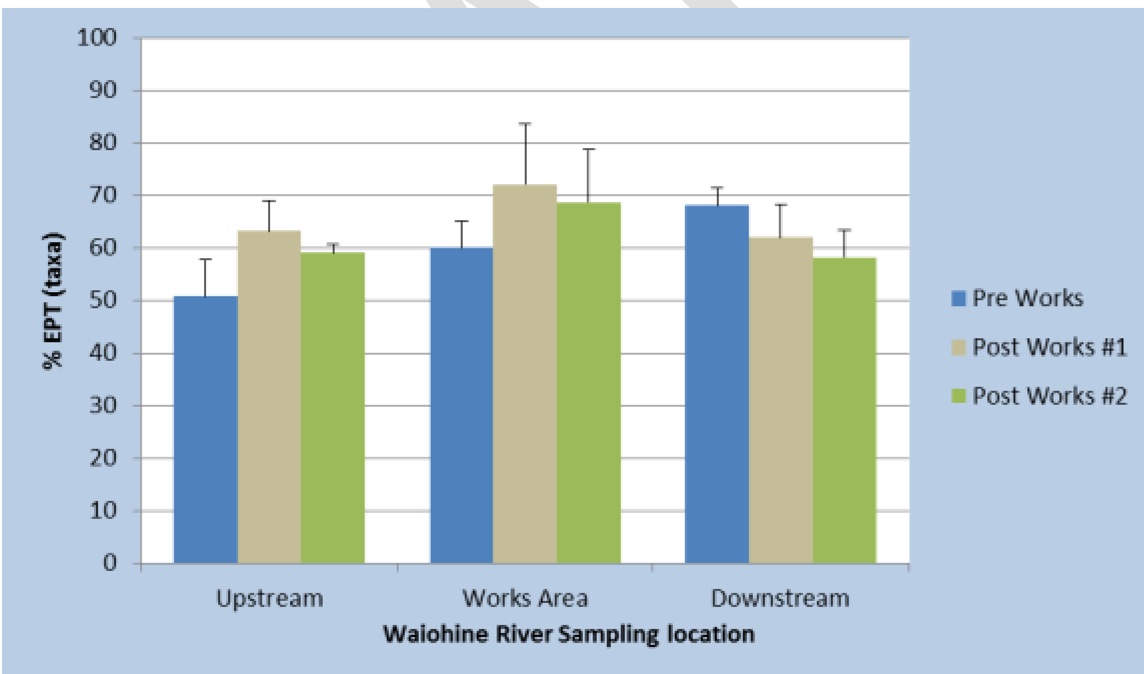




**Figure 24:** Mean (± 1 SE) A. % EPT (individuals) and B. % EPT (taxa) for sites sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012.

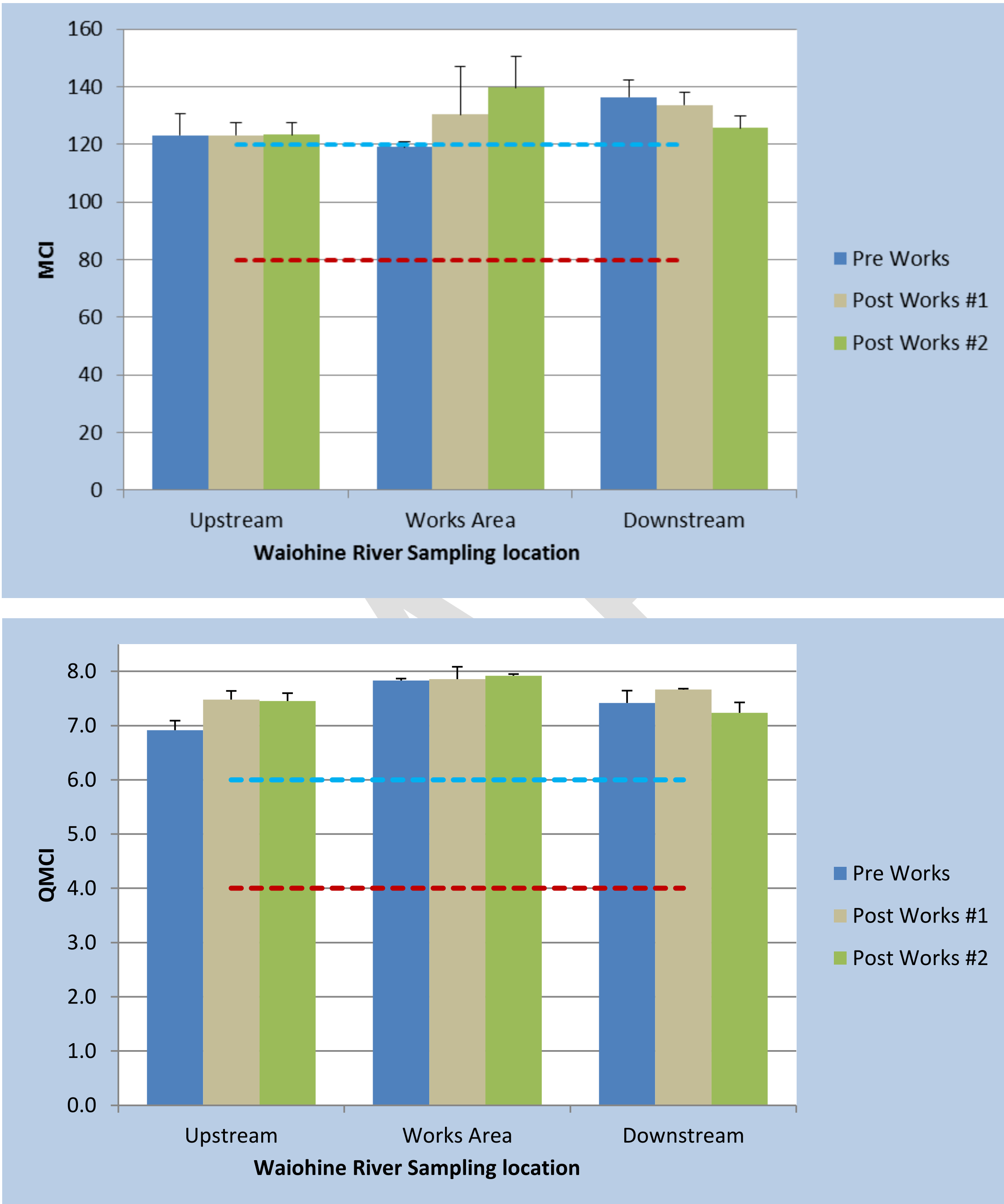



**Figure 25:** Mean (± 1 SE) A. MCI and B. QMCI for sites sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012. Thresholds indicative of good water quality are plotted as a blue dashed line and those of poor water quality as a red dashed line. (Refer Table 3).

The macroinvertebrate taxa collected at each site on the Waiohine River are presented in Appendix B and the relative abundance of the main groups of macroinvertebrates at these sites is presented in Figure 26. Communities at all sites were dominated by the mayfly *Deleatidium* sp. followed by Orthocladiinae. Changes in the relative abundances of the various taxonomic groups followed similar patterns at all three sites. This suggests these are changes unrelated to the river works.

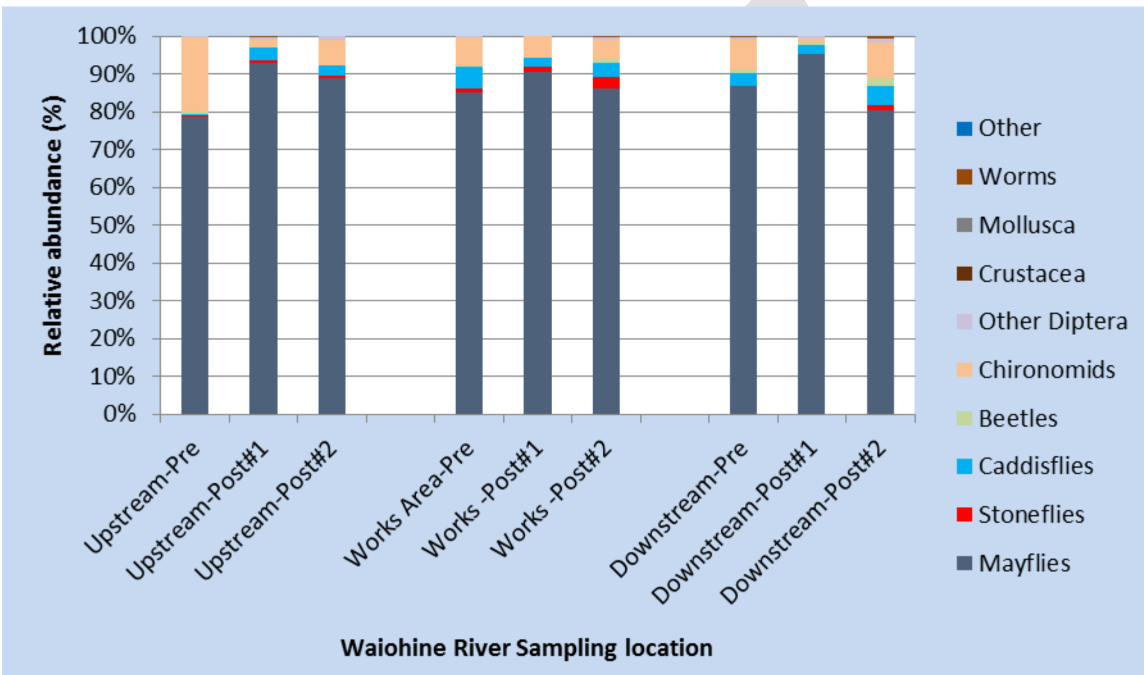



**Figure 26:** Relative abundance of the main taxonomic groups collected at sites sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012.

A plot of axis 1 against axis 2 from an NMDS ordination for sites sampled on the Waiohine River also shows macroinvertebrate communities at all sites regardless of sampling occasion to be similar to each other with the exception of communities at the works site immediately following the river works (circled on Figure 27). These results are similar to the Waingawa and show the river works in the Waiohine had an immediate effect but communities returned to their pre-works state within a three weeks and/or after the first fresh (250 $m^3$/s).

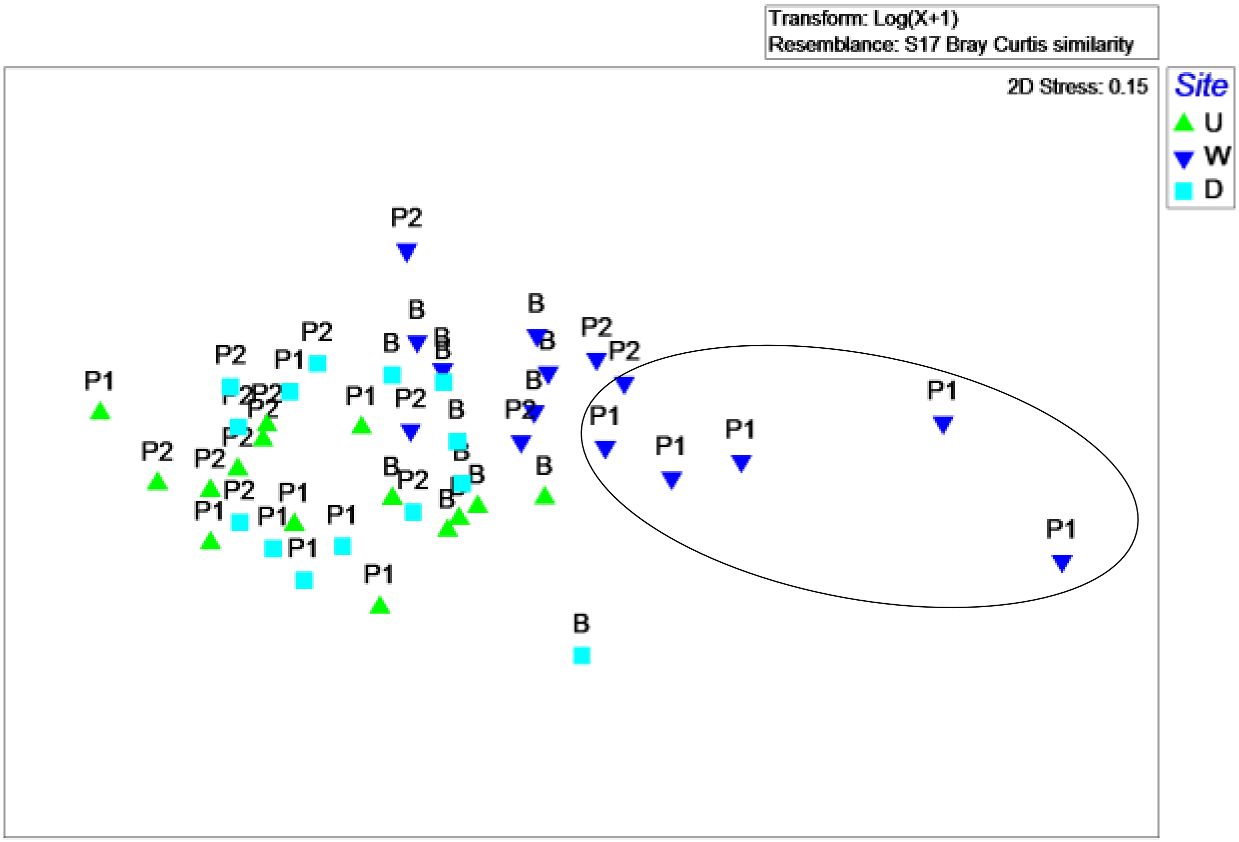



**Figure 27: P**lot of Axis 1 against Axis 2 from a Non Metric Multidimensional Scaling Ordination (Stress = 0.15) for sites sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012. U – upstream, W – works and D – downstream site; B – before, P1 – first post-works sampling and P2 – final post-works sampling after a fresh.



### *4.2.5. Fish communities*

Fish communities in the Waiohine River were similar to those found in the Waingawa River comprising bullies (*Gobiomorphus* sp.), torrentfish (*Cheimarrichthys fosteri*), eels (*Anguilla* sp.) and trout (*Salmo* sp.) (Figures 28-33).

Small Upland Bullies were the only species of fish collected at the works site, probably because of the slower deeper water and greater deposited sediment layers. Although they did decline in numbers collected after the works, a similar pattern was observed at the Upstream and Downstream sites so the decline could not be attributed to the works activity (Table 9). Similarly there were differences in the numbers of other fish species collected between the sites and sampling occasions but none of these could be attributed to the works or downstream sediment influx from the works. This again reflects the fact that areas where flood control engineering is carried out differ geomorphologically and hydrologically (hence the reason for the works) and that many of the species of fish present in adjoining reaches are not in these habitats because they are generally unsuitable. Nevertheless there is no evidence of any adverse effect of the works on fish in other reaches.

**Table 9:** P values for ANOVA comparing differences in fish (at the genus level) between sites and samplings for reaches sampled on the Waiohine River in relation to river works undertaken by GWRC in 2012. Significant values at P<0.05 are indicated in bold. The Site*Sample column is the critical one to identify any works effects over and above differences in site and sample time.

| | Site | Sample | Site * Sample |
|---|---|---|---|
| **Degrees of freedom** | 2,17 | 2,17 | 4,17 |
| **Number of fish** | **0.005** | **0.03** | 0.50 |
| **Number of taxa** | **0.03** | 0.31 | 0.78 |
| **Bullies** | **0.007** | **0.009** | 0.38 |
| **Eels** | **0.002** | **0.02** | **0.02** |
| **Torrentfish** | **0.009** | **0.01** | **0.02** |
| **Trout** | **0.04** | **<0.001** | **0.03** |

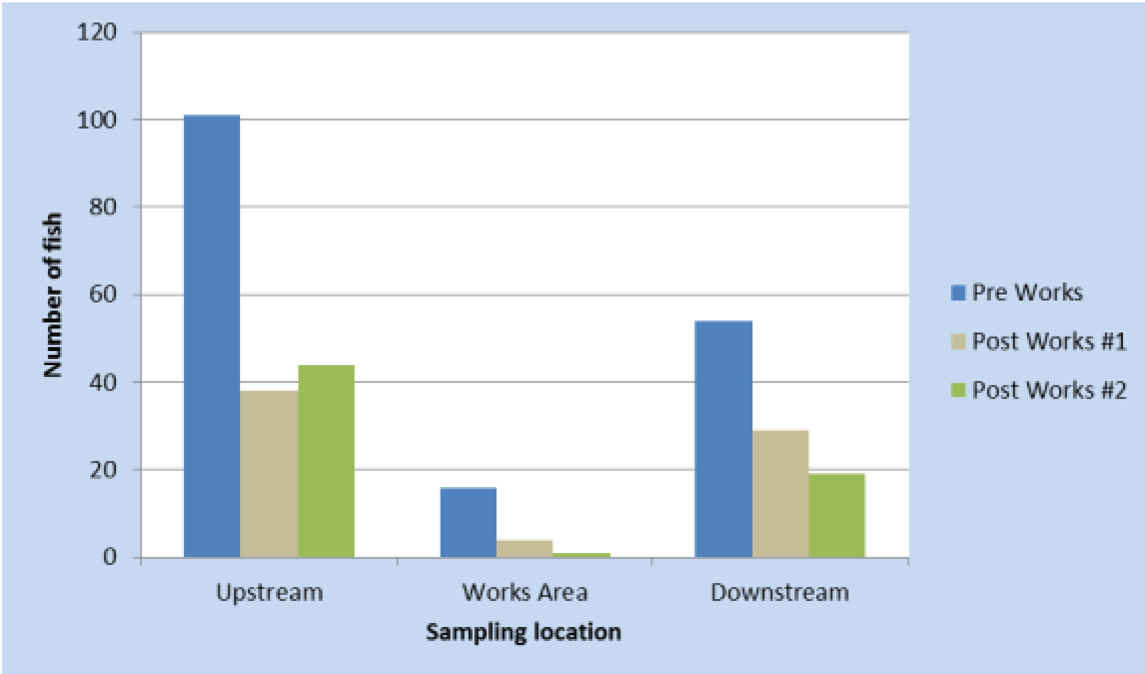



**Figure 28:** Number of fish collected on each sampling occasion in the Waiohine River in 2012.

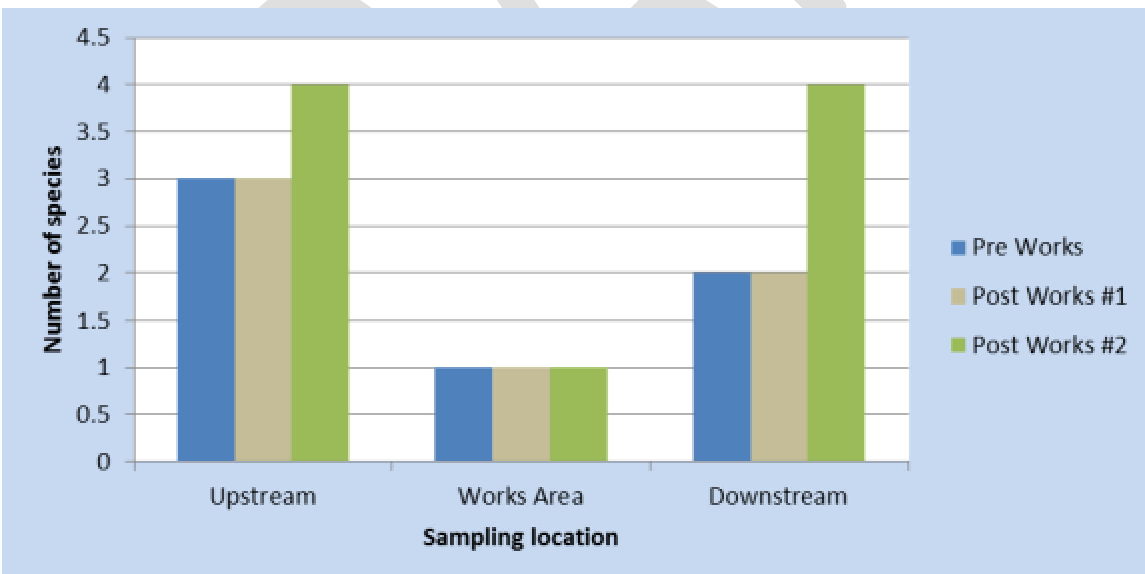



**Figure 29:** Number of species collected on each sampling occasion in the Waiohine River in 2012.

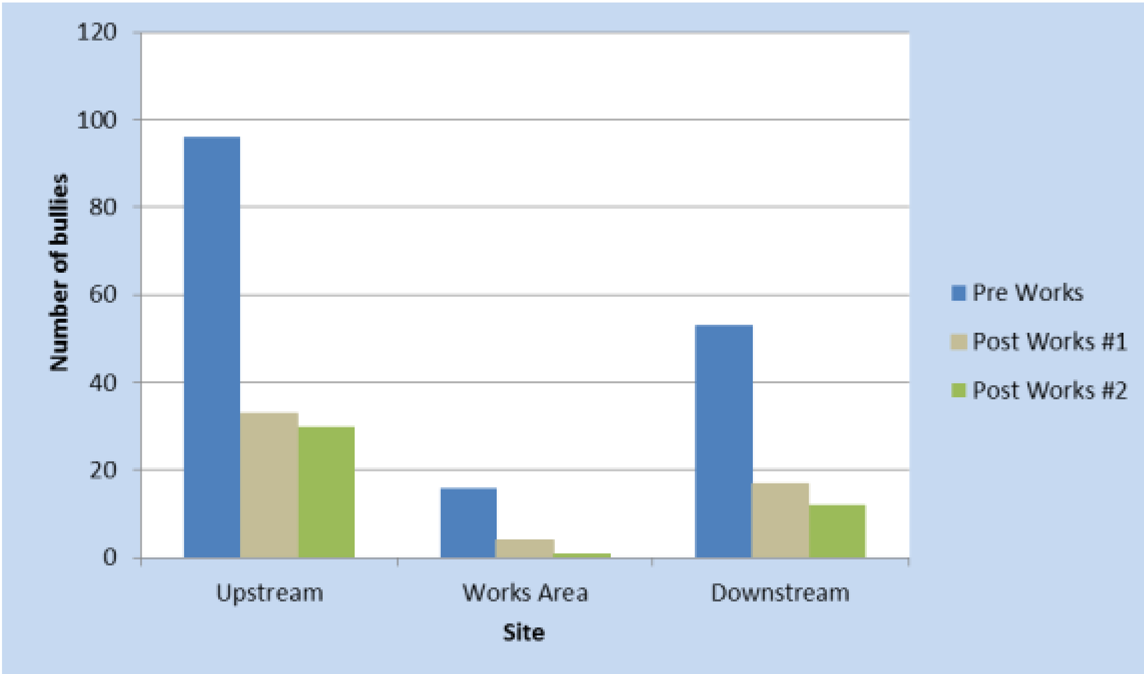



**Figure 30:** Numbers of bullies (*Gobiomorphus* sp.) present at each site sampled on the Waingawa River in 2012.

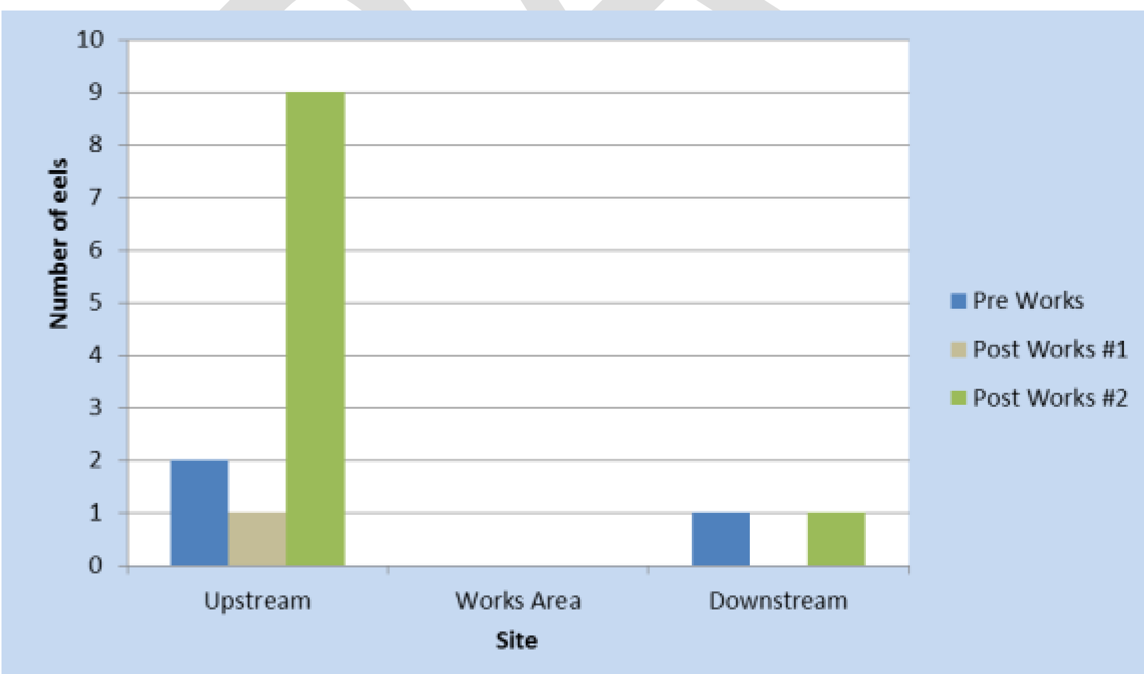



**Figure 31:** Numbers of eels (*Anguilla* sp.) present at each site sampled on the Waiohine River in 2012.

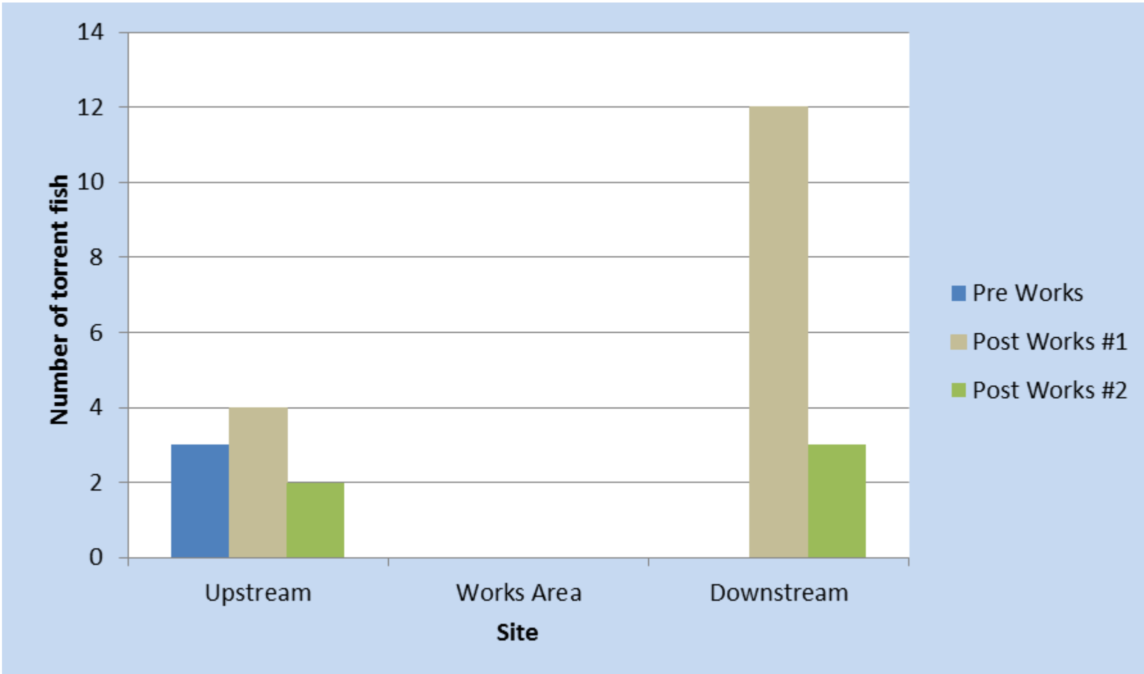



**Figure 32:** Numbers of torrentfish (*Cheimarrichthys fosteri*) present at each site sampled on the Waiohine River in 2012.

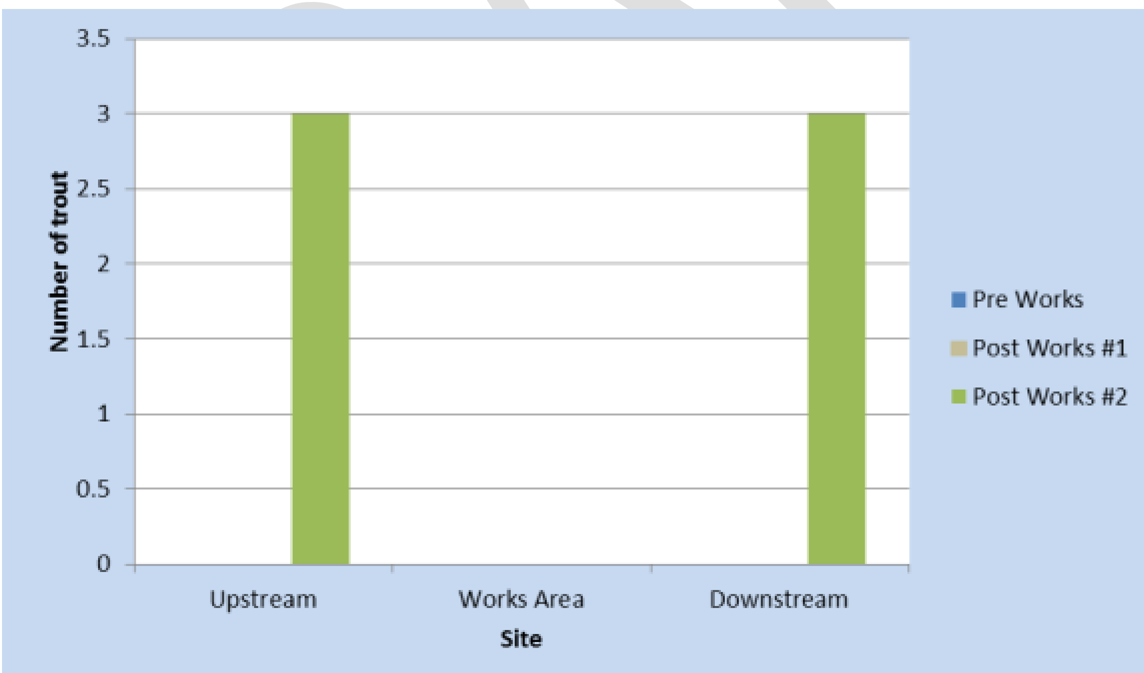



**Figure 33:** Numbers of trout (*Salmo* sp.) present at each site sampled on the Waiohine River in 2012.

### 4.3. Summary of Findings

River works carried out in a stretch of the Waiohine River in 2012 included the installation of rock groynes and bed recontouring. The engineering works had minimal effect on the habitat in the engineered reach of the river, although it was already very different from the reaches upstream and downstream. Any potential loss of habitat by the small changes in hydrology would be more than offset by habitat created by the rock groynes, although we did not directly assess the efficacy of this latter habitat.

Periphyton biomass was generally lower at the works reach but did decline further as a result of the works. It recovered at the works site to the seasonally expected higher biomass by the second post sample collection, although this was still lower than the periphyton biomass at the other two sites. Volumes of deposited sediment increased at all three sites (including upstream) immediately following the installation of the rock groynes. However these levels decreased again following the first fresh.

Numbers of macroinvertebrates and taxa, and percentage of EPT (individuals) declined immediately following the works but had recovered to pre-engineering levels when sampled 20 days after the first major fresh. None of the other biological metrics changed at all. Community composition was also altered by the engineering works but had recovered by the last sample collection.

Bullies were the only species found at the works site on all sampling occasions and although they did decline in abundance just after the works this also occurred at the upstream and downstream sites and is thus probably unrelated to the engineering works. As the hydrology and geomorphology of the works site was quite different from the upstream and downstream sites (hence the need for the works) there were no eels, torrentfish or trout and the effect of the works on them is unknown. There were no apparent changes to the abundances of these fish downstream that could be attributed to the works.

Analysis of the in-stream communities and habitats indicated that the river works did have an effect on the stretch of the Waiohine River where the works occurred, however, as with the Waingawa, this effect was temporary. On the first sampling following a sizeable fresh (250 $m^3/s$) all of the measured variables were similar to those found upstream. It would seem that the first major fresh resets any effects of minor works such as those investigated in the Waiohine.

# 5. Ruamahanga River

## 5.1. Background

The Ruamahanga River originates in the Tararua Ranges northwest of Masterton and covers a catchment area of approximately 3,470 sq. km. It flows for approximately 130 km through open country in the Wairarapa until it meets Cooks Strait on the shores of Palliser Bay. It has a number of large tributaries draining into it including the Waingawa and Waiohine Rivers.

GWRC undertook river management works in an area of the Ruamahanga River downstream of SH2, to the south of Masterton at GWRC river cross section 233+150m to 233+270m (Figures 34-35). Works included 120 m of bed recontouring completed on 29 April 2013 and the installation of rock groynes for a river length of 30 m on 03 May 2013.

The work was required to maintain design river alignment. Within this area of the Ruamahanga River there are a number of critical assets, including a 1-in-100 year stopbank and the Masterton Wastewater Treatment Plant irrigation fields directly downstream from the work site. Therefore, river alignment and erosion control is a critical function of the river scheme at this site.

The pre-work sample was completed in late February 2013. Work was delayed due to a consent requirement to avoid in-stream work during low flows until late April 2013. No significant freshes occurred during this time and no significant natural changes occurred to the river during this time. The post-works collection was made 9th May 2013. A second post-works sampling was not possible as flow conditions subsequent to the first post-works sample collection made sampling too difficult.

Examples of the sites sampled on the Ruamahanga River in 2013 are shown in Plates 14-17.


**Figure 34:** Map of Ruamahanga River showing general area where river works were undertaken by GWRC (indicated by red arrow).

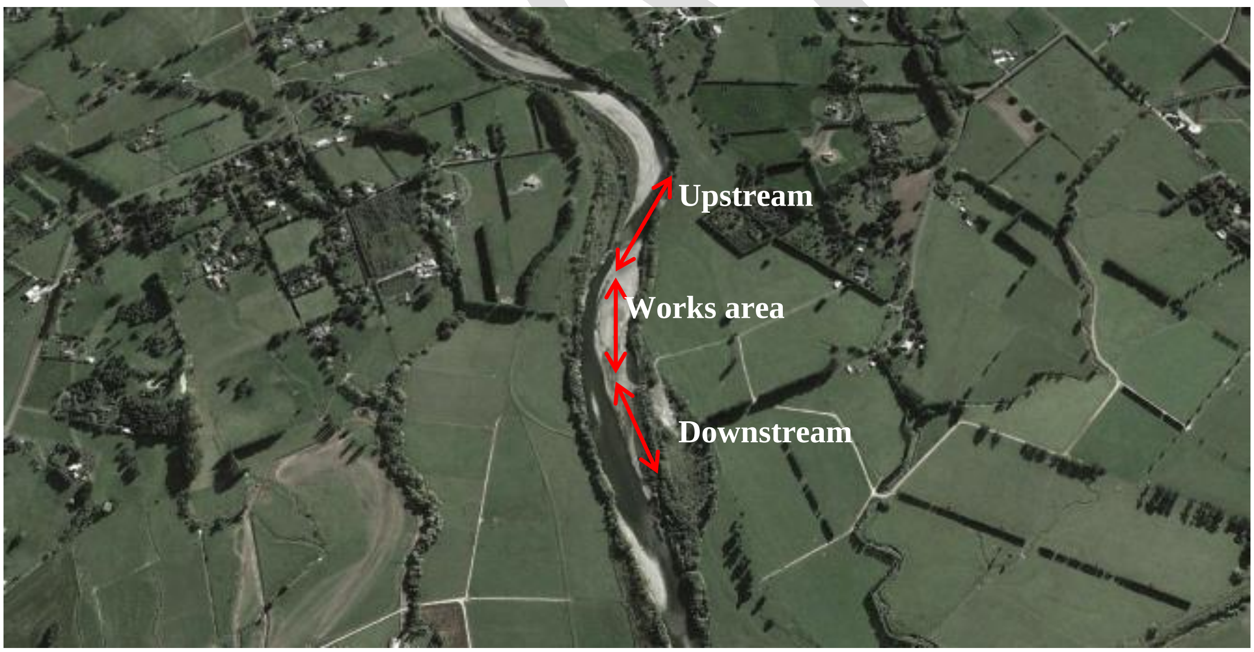



**Figure 35:** Map showing sites sampled on the Ruamahanga River in 2013.

**Plate 14:** Ruamahanga River upstream of stretch where works were carried out in 2013.

**Plate 15:** Stretch of Ruamahanga River where rock groynes were installed in 2013.

**Plate 16:** Rock groynes in the Ruamahanga River.

**Plate 17:** Ruamahanga River downstream of stretch where works were carried out in 2013.

## 5.2. Data Analysis

### *5.2.1. Habitat characteristics*

The habitat characteristics recorded at each of the sites on the Ruamahanga River are presented in Table 10 and a hydrograph for the study period presented in Figure 36.

All sites were characterised as runs containing mostly small cobbles and pebbles, approximately 30-50 cm deep, 15-25 m wide, with conductivity ranging from 114 to 174 µS/cm and flow between 0.2 and 1.4 m/s.

The delay between the pre-works sampling and, the actual works and subsequent post-works sampling was longer than would be ideal. As a result flow in the river had increased from 0.7 $m^3$/s to 4.5 $m^3$/s. However any effect of flow will be seen at all 3 sites whereas any works effect would only be evident at the works or downstream site.

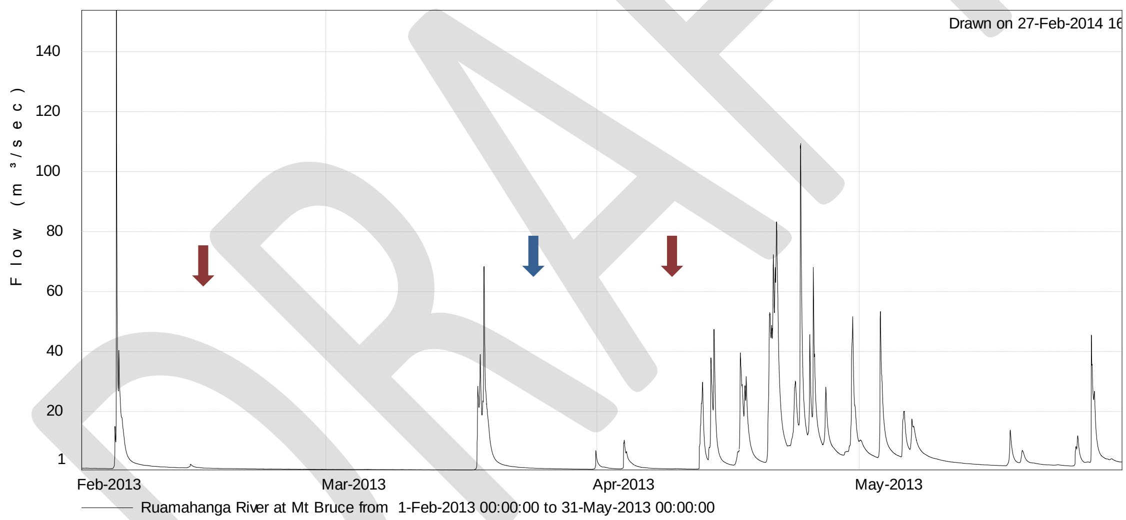



**Figure 36:** Hydrograph of Ruamahanga River recorded at Mt Bruce for the period of engineering (blue arrow) and sampling (red arrow). Note there is no second post-works sampling.

**Table 10:** Environmental characteristics of sites sampled near river management works areas on the Ruamahanga River in 2013.

| | Upstream | | Works Area | | Downstream | |
|---|---|---|---|---|---|---|
| | Pre Works | Post Works #1 | Pre Works | Post Works #1 | Pre Works | Post Works #1 |
| Date sampled | 20/02/2013 | 9/05/2013 | 20/02/2013 | 9/05/2013 | 20/02/2013 | 9/05/2013 |
| Easting | 2735864 | 2735864 | 2735778 | 2735778 | 2735873 | 2735873 |
| Northing | 6022179 | 6022179 | 6022054 | 6022054 | 6021620 | 6021620 |
| **Chemical** | | | | | | |
| Conductivity (µS/cm) | 166 | 114 | 174 | 118 | 163 | 114 |
| Temperature (°C) | 19 | 10 | 23 | 11 | 24 | 12 |
| **Physical** | | | | | | |
| Mean Width (m) | 25 | | 25 | | 15 | |
| Mean Depth (cm) | 32 | 40 | 49 | 36 | 46 | 38 |
| Mean Velocity (m/s) | 1.37 | 0.71 | 0.19 | 1.07 | 0.00 | 0.66 |
| **Substrate** | | | | | | |
| Embeddedness | Loose | Loose | Loose | Loose | Loose | Loose |
| % Boulders (>300 mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| % Large Cobbles (129 - 300 mm) | 10 | 5 | 5 | 19 | 5 | 5 |
| % Small Cobbles (65 - 128 mm) | 60 | 35 | 40 | 38 | 20 | 20 |
| % Pebbles (17 - 64 mm) | 20 | 35 | 40 | 38 | 50 | 20 |
| % Gravel (8 -16 mm) | 5 | 35 | 7.5 | 2.5 | 0 | 50 |
| % Sand (< 8 mm) | 5 | 0 | 7.5 | 2.5 | 25 | 5 |
| **Flow Type / flow present on sample day at Mt Bruce** | 0.7 $m^3/s$ | 4.5 $m^3/s$ | 0.7 $m^3/s$ | 4.5 $m^3/s$ | 0.7 $m^3/s$ | 4.5 $m^3/s$ |
| % Pool | 0 | 0 | 0 | 0 | 0 | 0 |
| % Run | 20 | 100 | 100 | 100 | 100 | 100 |
| % Riffle | 80 | 0 | 0 | 0 | 0 | 0 |
| %Rapid | 0 | 0 | 0 | 0 | 0 | 0 |
| Undercutting | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Debris jam | 0 | 0 | 0 | 0 | 0 | 0 |
| Overhead cover | 0 | 0 | 0 | 0 | 0 | 0 |
| Macrophyte cover (%) | 0 | 1 | 0 | 0 | 0 | 0 |

### *5.2.2. Periphyton*

Mean periphyton biomass ranged from 0.3 mg/m$^2$ to 16.4 mg/m$^2$.

Upstream and downstream sites followed similar patterns with decreasing levels of periphyton over time (Figure 37).

Periphyton biomass all but disappeared at the works site following the engineering.

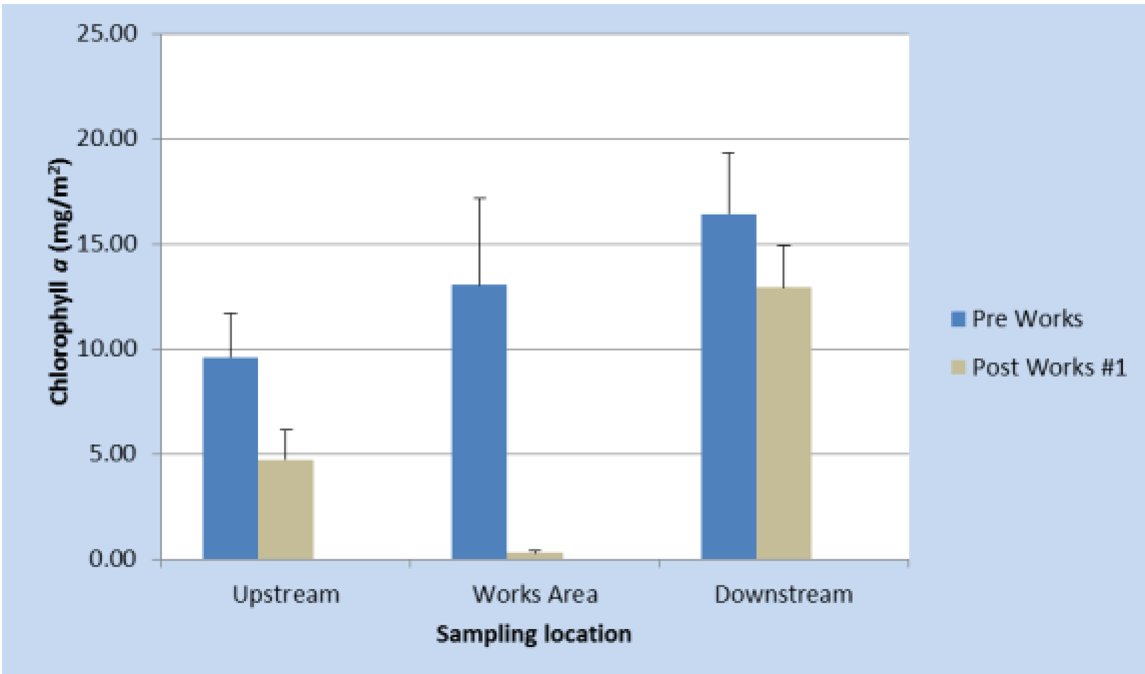



**Figure 37:** Mean periphyton biomass, measured as chlorophyll *a* (mg/m$^2$), for sites sampled on the Ruamahanga River in 2012.

### *5.2.3. Deposited sediment*

Volume of deposited sediment increased from upstream to downstream in the three stretches of the Ruamahanga River sampled prior to any works being undertaken (Figure 38). Increases in deposited sediment did occur between samplings but these were not significant and are unlikely to be a result of the works.

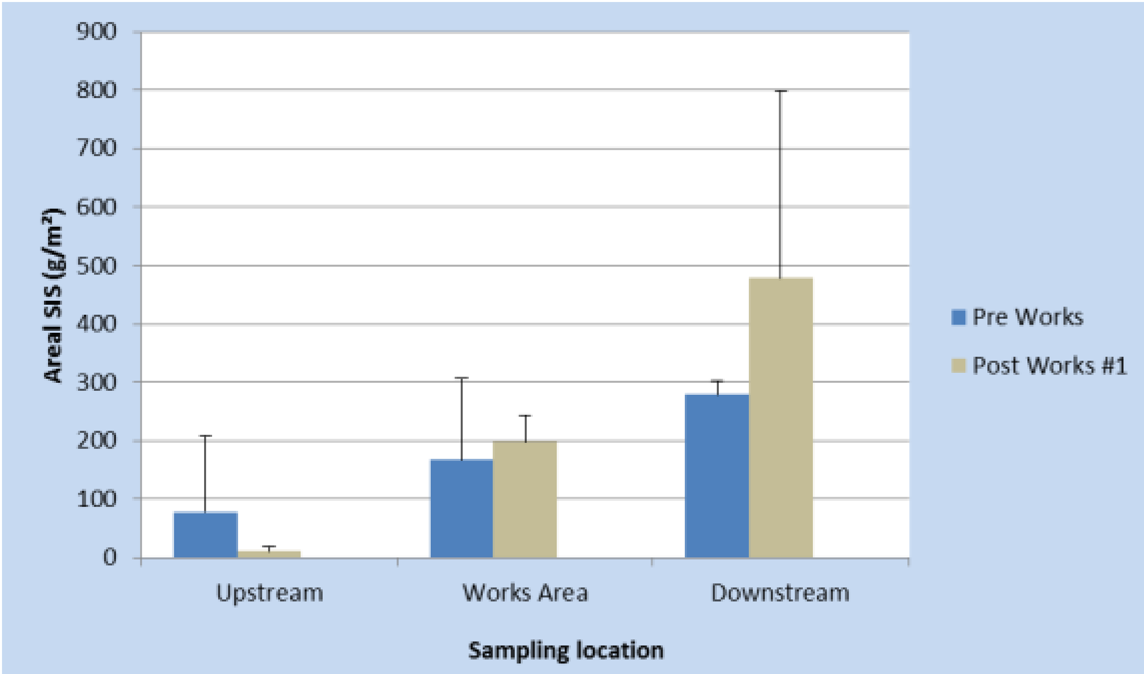



**Figure 38:** Areal deposited inorganic sediment (g/m$^2$) at sites sampled on the Ruamahanga River in 2013.

### *5.2.4. Macroinvertebrate communities*

Biotic indices for the sites sampled on the Ruamahanga River are presented in Figure 39-41.

While there were significant differences in most macroinvertebrate variables these occurred at all sites and are thus attributable to the increase in flows or change in time between the samplings, not the result of the river engineering works (Table 11).

**Table 11:** P values for ANOVA comparing differences in biotic indices between sites and samplings for reaches sampled on the Ruamahanga River in relation to river works undertaken by GWRC in 2012. Significant values at P<0.05 are indicated in bold. The Site*Sample column is the critical one to identify any works effects over and above differences in site and sample time.

| | **Site** | **Sample** | **Site * Sample** |
|---|---|---|---|
| **Degrees of freedom** | *2,24* | *1,24* | *2,24* |
| **Number of individuals** | 0.29 | **0.002** | 0.53 |
| **Number of taxa** | **< 0.001** | 0.07 | **0.01** |
| **% EPT (individuals)** | **< 0.001** | **< 0.001** | **< 0.001** |
| **% EPT (taxa)** | **< 0.001** | **< 0.001** | 0.50 |
| **MCI** | **< 0.001** | **0.01** | 0.10 |
| **QMCI** | **< 0.001** | **< 0.001** | **< 0.001** |
| **Chlorophyll *a*** | **0.01** | **0.002** | 0.14 |
| **Deposited sediment** | **0.01** | 0.48 | 0.36 |

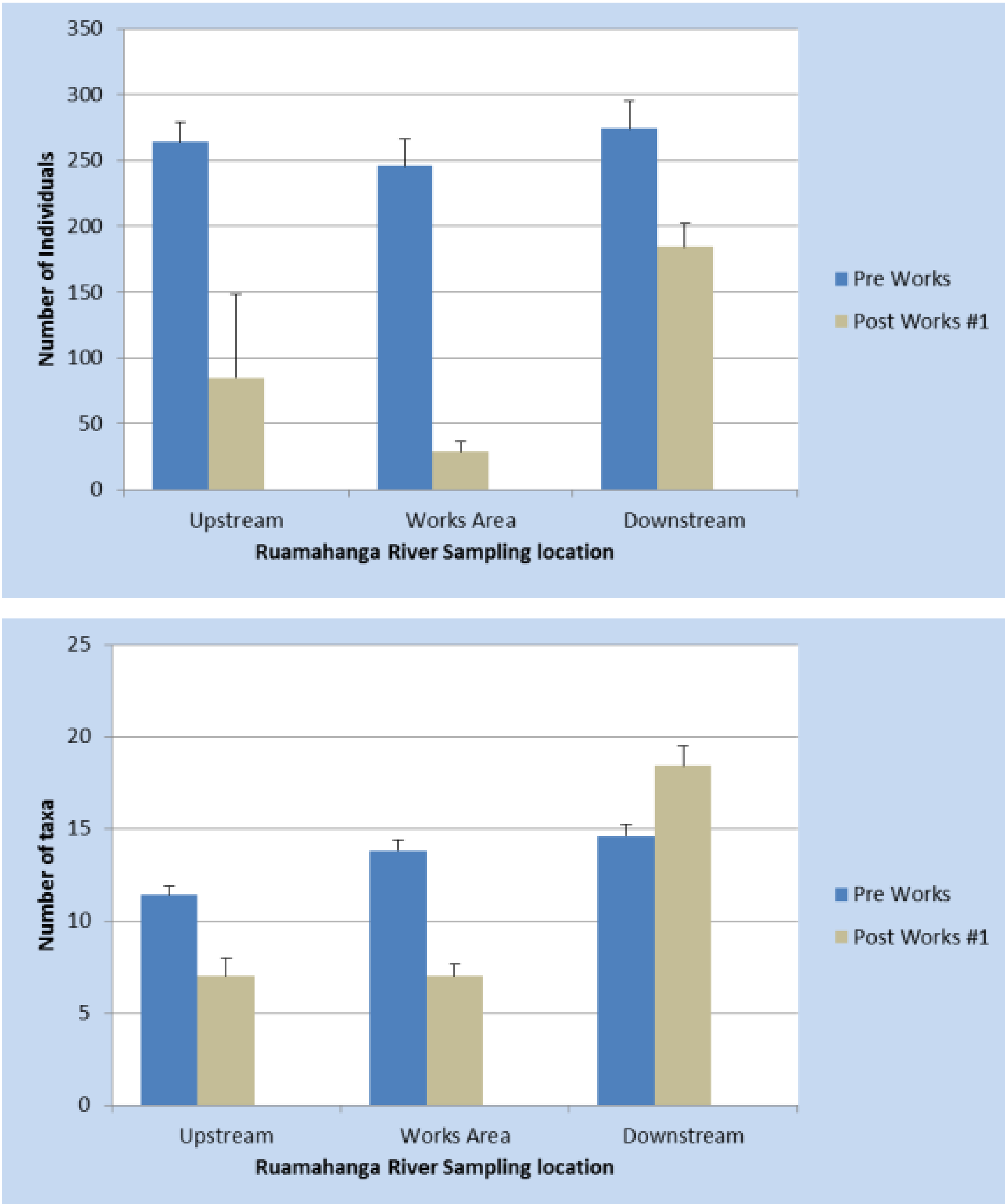
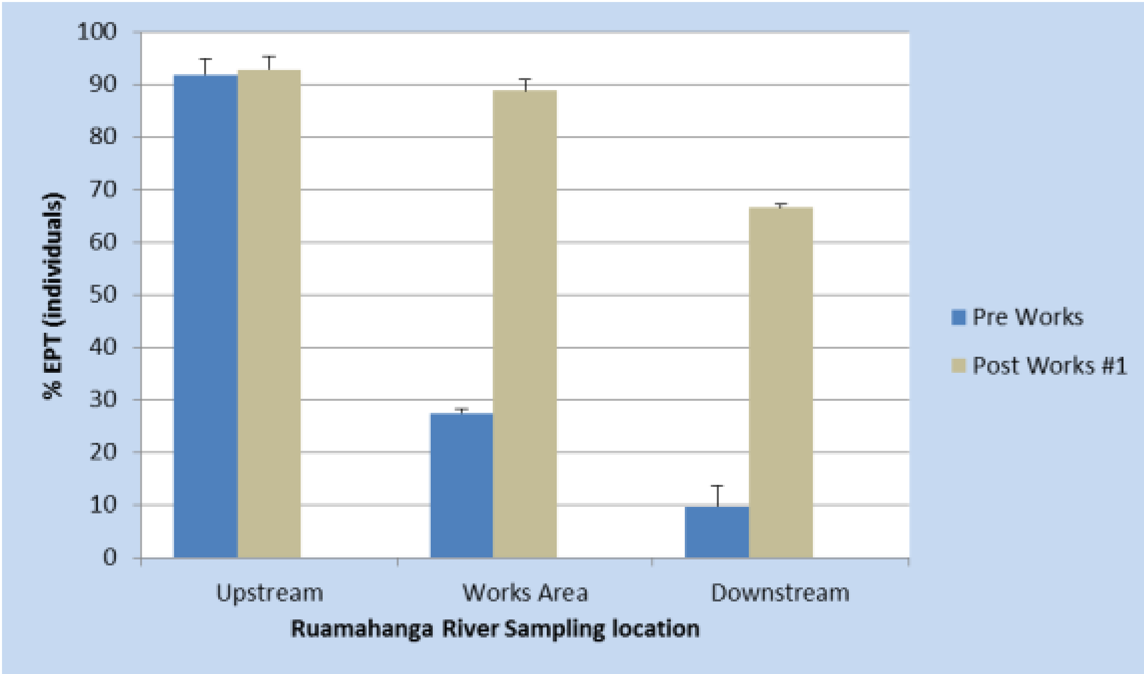



**Figure 39:** Mean (± 1 SE) A. Number of individuals and B. Number of taxa for sites sampled on the Ruamahanga River in relation to river works undertaken by GWRC in 2013.



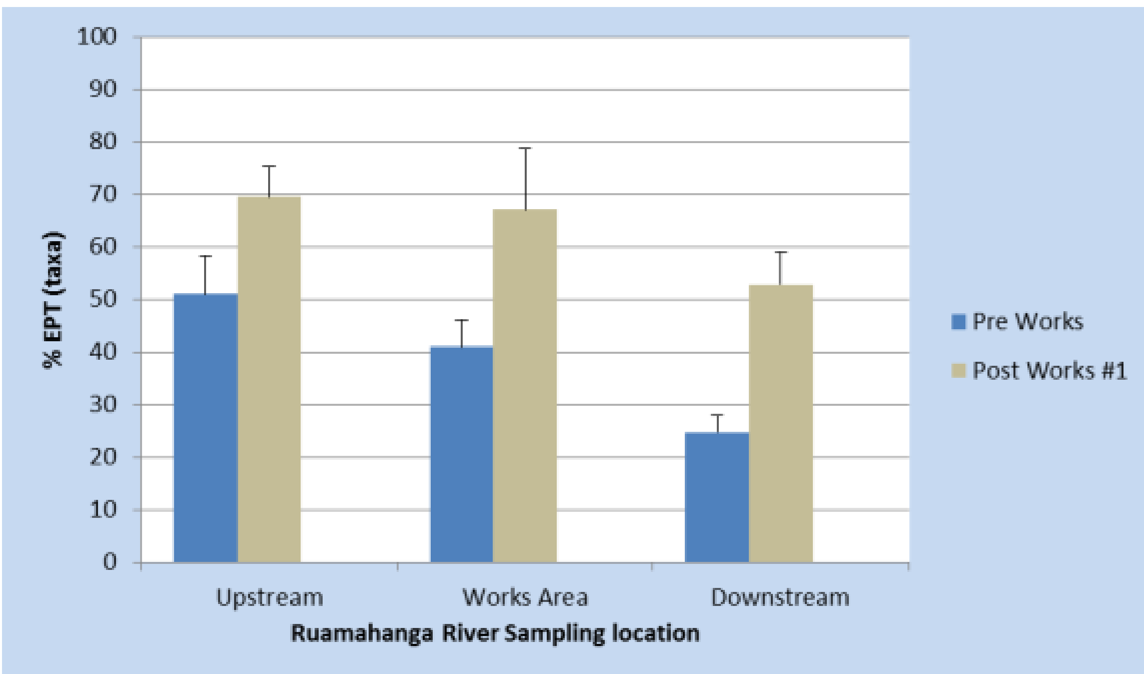




**Figure 40:** Mean (± 1 SE) A. % EPT (individuals) and B. % EPT (taxa) for sites sampled on the Ruamahanga River in relation to river works undertaken by GWRC in 2013.

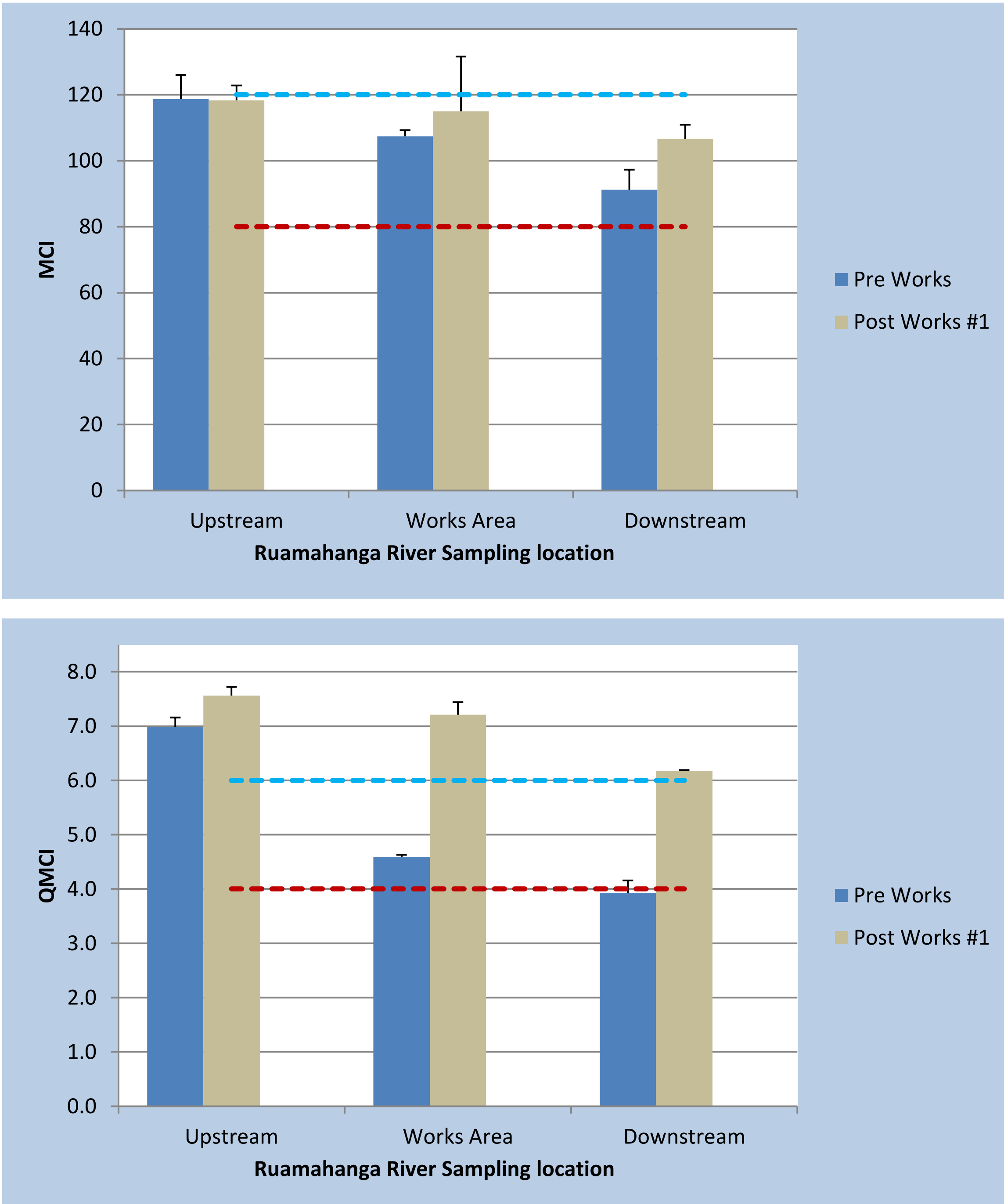



**Figure 41:** Mean (± 1 SE) A. MCI and B. QMCI for sites sampled on the Ruamahanga River in relation to river works undertaken by GWRC in 2013. Thresholds indicative of good water quality are plotted as a blue dashed line and those of poor water quality as a red dashed line. (Refer Table 3).

The macroinvertebrate taxa collected at each site are presented in Appendix C and the relative abundance of the main groups of macroinvertebrates at these sites is presented in Figure 42. Communities at the upstream site were dominated by the mayfly *Deleatidium* sp. with the caddis *Aoteopsyche* sp. also common at both pre and post works samplings. Communities at the works and downstream sites were dominated by chironomids prior to river works taking place, but then replaced by the mayfly *Deleatidium* sp. at the works site and caddisflies and the beetle Elmidae downstream following the works.

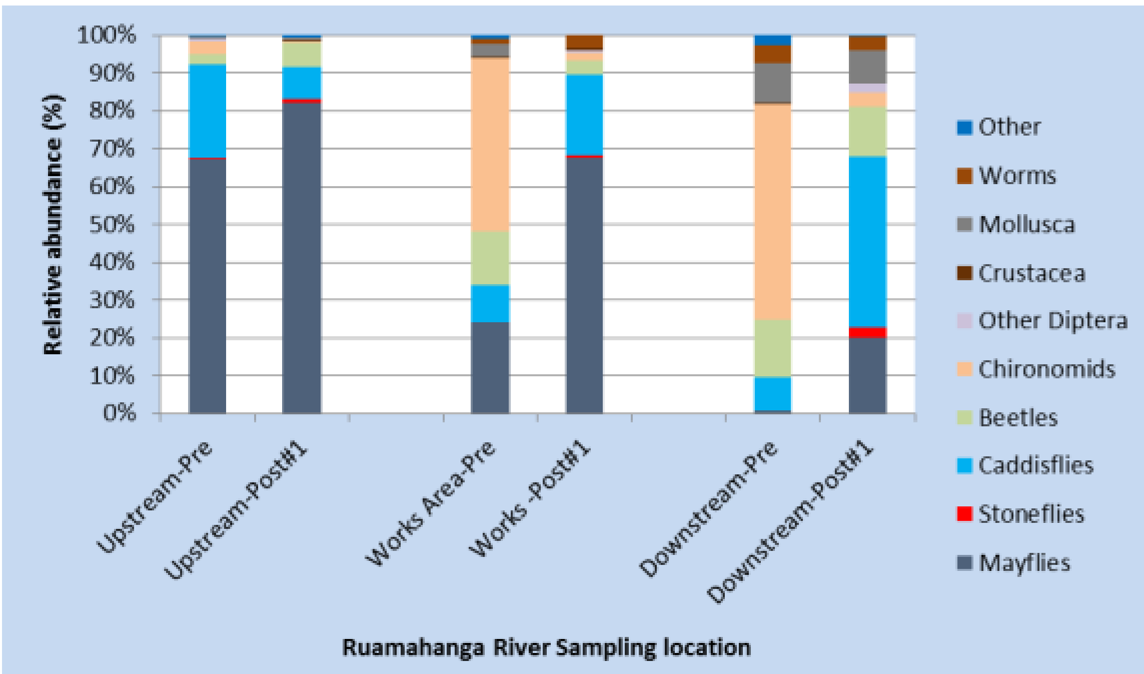



**Figure 42**: Relative abundance of the main taxonomic groups collected at sites sampled on the Waingawa River in relation to river works undertaken by GWRC in 2012.

A plot of axis 1 against axis 2 from an NMDS ordination for sites sampled on the Ruamahanga River shows a difference in macroinvertebrate communities between sites and samplings (Figure 43). The upstream and works sites are more similar to each other at the post works sampling while the works and downstream sites are more similar to each other prior to works being undertaken.

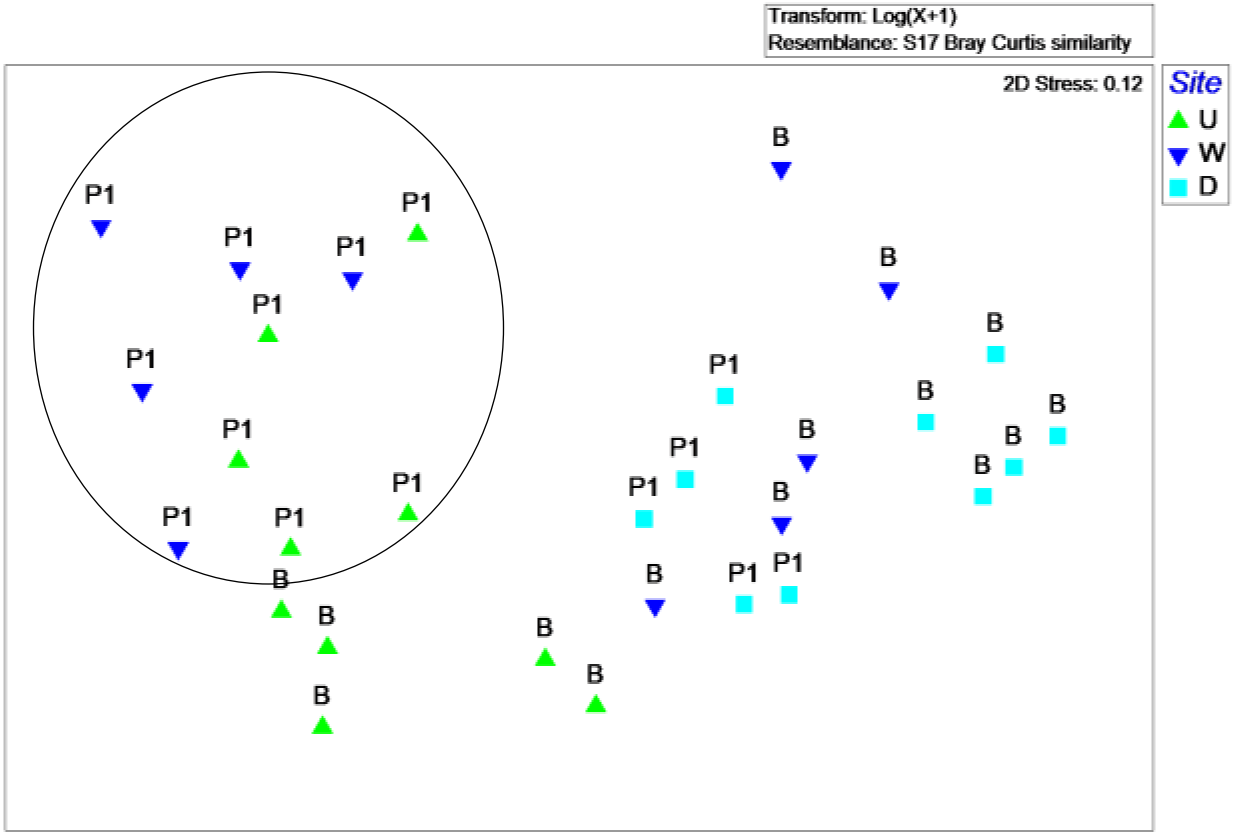



**Figure 43: P**lot of Axis 1 against Axis 2 from a Non Metric Multidimensional Scaling Ordination (Stress = 0.12) for sites sampled on the Ruamahanga River in relation to river works undertaken by GWRC in 2013. U – upstream, W – works and D – downstream site; B – before, P1 – first post-works sampling and P2 – final post-works sampling after a fresh.

### *5.2.5. Fish communities*

Both the number of fish and the number of species at the upstream and works sites declined between pre and post works samplings. Interestingly the number of fish (predominantly Bullies) at the downstream site increased after the works (Figures 44-47).

Fish communities in the stretch of the Ruamahanga were dominated by Bullies (Upland and Common Bullies) and eels (*Anguilla* sp.). Following the installation of the groynes, numbers of bullies decreased at the upstream and works sites while the number of eels here increased. The opposite occurred at the downstream site with bully numbers increasing. Thus numbers of Bullies increased and eels decreased downstream as a result of the engineering works but only the result for eels was statistically significant (Table 12).

**Table 12:** P values for ANOVA comparing differences in fish (at the genus level) between sites and samplings for reaches sampled on the Ruamahanga River in relation to river works undertaken by GWRC in 2012. Significant values at P<0.05 are indicated in bold. The Site*Sample column is the critical one to identify any works effects over and above differences in site and sample time.

| | *Site* | *Sample* | *Site * Sample* |
|---|---|---|---|
| **Degrees of freedom** | *2,6* | *1,6* | *2.6* |
| **Number of fish** | 0.20 | 0.45 | 0.31 |
| **Number of taxa** | 0.28 | 0.12 | 1.0 |
| **Bullies** | 0.10 | 0.90 | 0.30 |
| **Eels** | **0.047** | 1.00 | **0.02** |

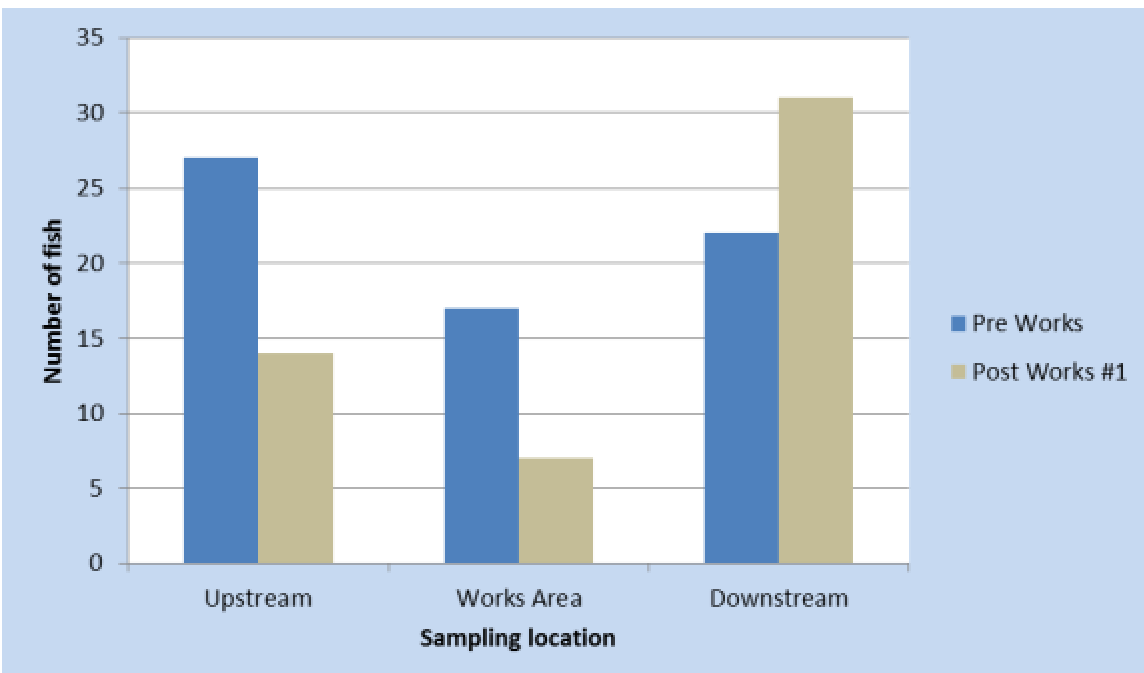



**Figure 44:** Number of fish collected on each sampling occasion in the Ruamahanga River in 2013.

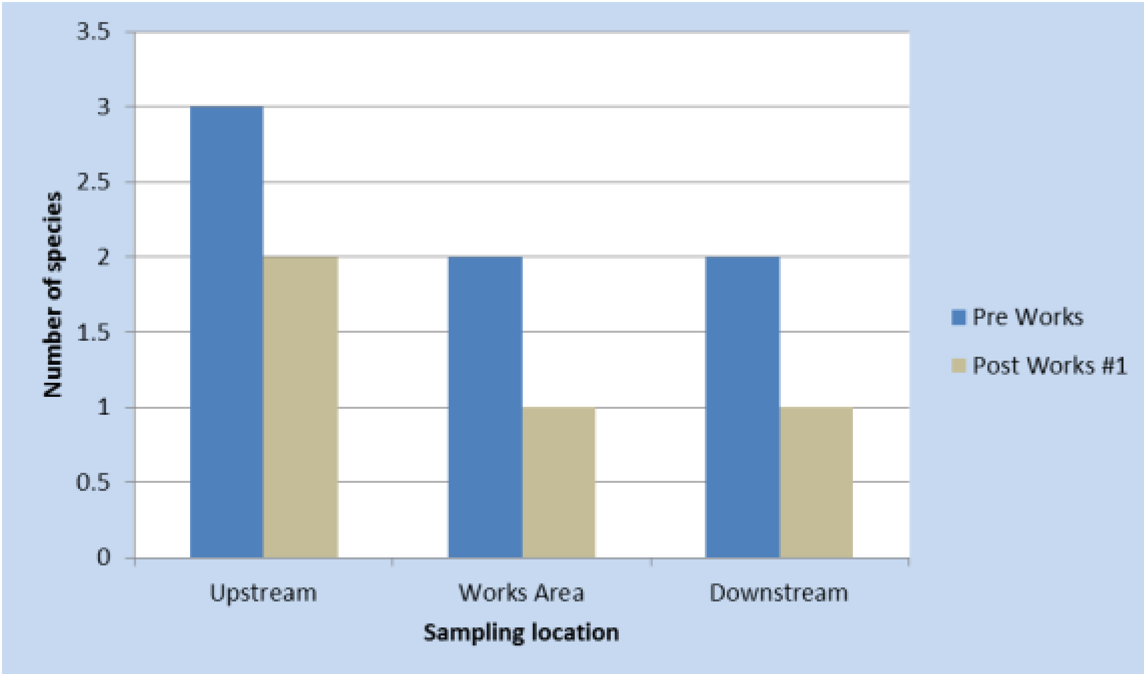



**Figure 45:** Number of species collected on each sampling occasion in the Ruamahanga River in 2013.

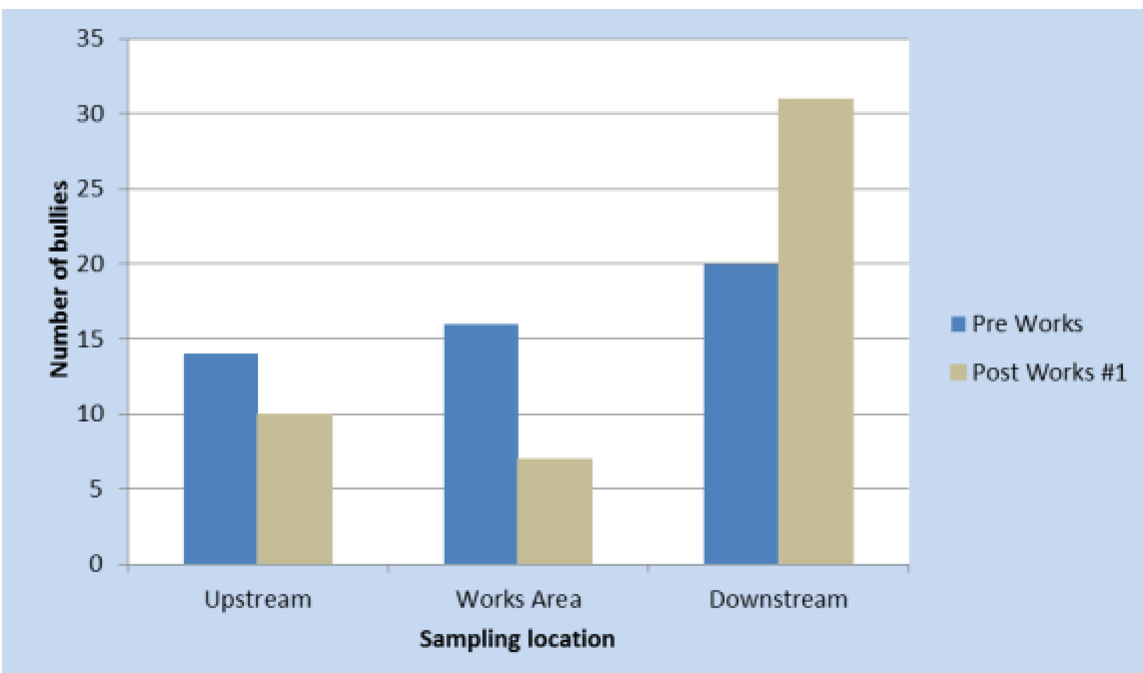



**Figure 46:** Numbers of bullies (*Gobiomorphus* sp.) present at each site sampled on the Ruamahanga River in 2013.

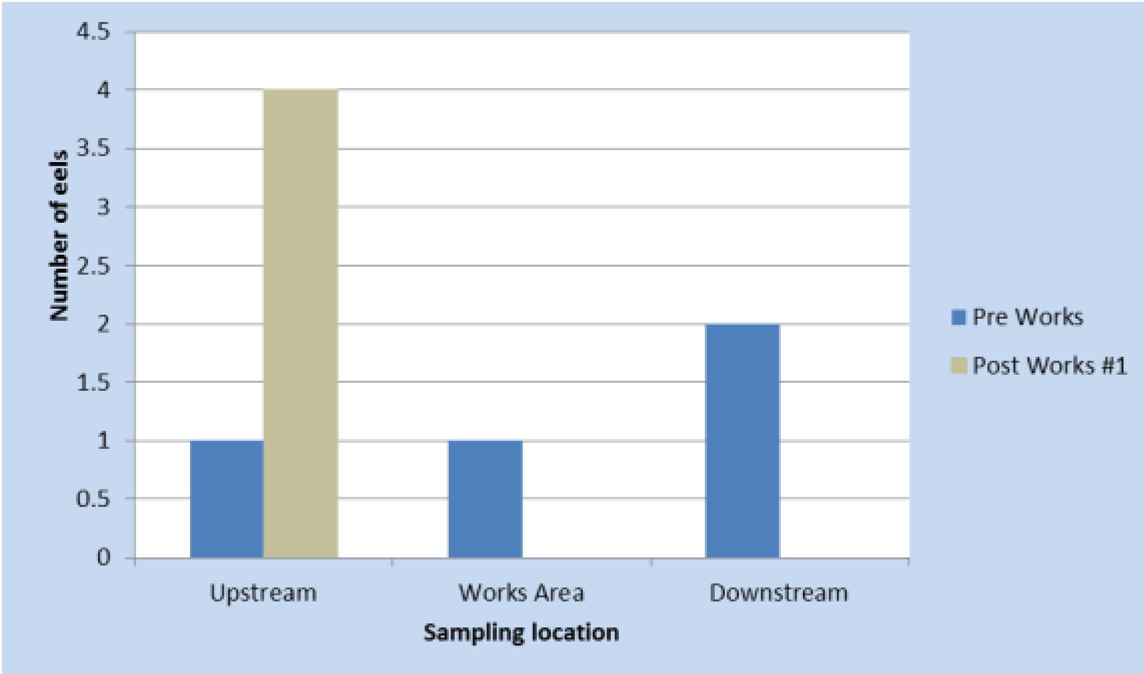



**Figure 47:** Numbers of eels (*Anguilla* sp.) present at each site sampled on the Ruamahanga River in 2013.

### 5.3. Summary of Findings

River works carried out in a stretch of the Upper Ruamahanga River in 2013 included the installation of rock groynes and bed recontouring. The pre-works sample was collected in February but because of low flows the works were not completed until April when the post-works sample was collected. Following that flows were too high for safe sampling. This certainly complicates the conclusions we can draw from this investigation, however because we have a BACI design the effect of the time interval between samplings can be corrected for by the sampling at the upstream site.

Habitat changes were minimal. Neither periphyton biomass nor volume of deposited sediment was affected by the works activity at either the works or downstream sites.

Although the macroinvertebrate communities did change with the increase in flows or change in time between the samplings, there was no evidence it was a result of the river engineering works.

Again the benthic fish communities appeared to be unaffected by the engineering works with eels being the only taxa to show an effect, individuals increasing downstream of the works. Although it should be noted that only bullies (two species) and eels were found by our electrofishing at these Ruamahanga sites.

# 6. Discussion and Recommendations

## 6.1. Discussion

This research attempted to carefully examine the effects of typical Regional Council river engineering practices in three Wairarapa rivers (the Waingawa, Waiohine and Ruamahanga) in 2012 and 2013. Works were applied to approximately 100 m length reaches in each of the rivers, and included the installation of rock groynes, bed recontouring and some beach disturbance.

We adopted the most rigorous design possible with a Before After Control Impact design and sampled upstream (as a control) and downstream of the works area in reaches that resembled the hydrogeomorphic conditions at the works reach site as closely as possible. However, the fact that the reaches needed engineering in the first place was because they were different from those upstream and downstream in hydrogeomorphology. Furthermore in the last case study there was a considerable interval before and after sampling.

Despite the difficulties of conducting such studies in the real world, the conclusions from this work are as scientifically rigorous as can possibly be achieved.

In general we would conclude that the weight of evidence from all 3 studies strongly indicates a minimal ("less than minor") effect of these kinds of engineering activities. This can be attributed to a number of factors including the activities were relatively small and discrete (no consideration of cumulative effects was made), this type of activity (despite the increased turbidity and substrate movement) is not dramatically dissimilar to the physical effects of a fresh or flood, which are common in all three rivers, and that such activities have occurred in these rivers (along with other anthropogenic disturbances) for many years. Although, the observed effects did scale with the scale of the engineering activity, so that the Waingawa which had the greatest length and severity of works exhibited the biggest ecological effect. However, even here the number of macroinvertebrates and trout were the only biological parameters that were still "affected" at the final sampling after the first major fresh.

The bulldozer activity certainly increased the turbidity of water during the works activity (personal observation). Volumes of deposited sediment as a result increased at the works sites immediately following the works in both the Waiohine and Ruamahanga Rivers but decreased at the works site in the Waingawa. Deposited sediment levels just downstream of the works area also increased in all three rivers as a result of in-stream works. However, after the first major fresh or flood the sediment was flushed out.

Periphyton biomass decreased at the works sites on all three rivers as a direct result of the in-stream river works and/or the increased deposited sediment. But again after the first fresh the biomass levels were not different from those upstream or downstream of the works area.

Invertebrate communities in both the Waingawa and Waiohine Rivers were affected by the works activity, either directly from the engineering action, or the associated increase in deposited sediment and decrease in periphyton biomass. All but the total number of invertebrates at the

Waingawa River had returned to pre-works levels after the first fresh. Macroinvertebrate communities in the Ruamahanga River were not affected by the works activity.

The effects on the fish communities were the most difficult to evaluate, as because of the differences in hydrogeomorphology between the reaches the fish communities collected with the electrofishing were different between the works and the upstream and downstream sites even before the engineering works took place. Thus torrentfish were not present at some works sites and the effects of the engineering on them could not really be evaluated (although if they were not present I guess they couldn't be affected). Again the weight of the evidence provides no indication that any fish (except trout in the Waingawa River) were adversely affected by the engineering activities, in fact eels and/or bullies in some of the rivers increased in abundance.

Some of the works activities, such as creation of boulder groynes, and the retention of backwater areas should probably have increased good habitat for many fish, although we did not evaluate these directly. Allowing a backwater to develop in the old channel and remain connected to the mainstem has certainly added potential instream habitat for a variety of fish species. The Flood Protection work did, in this case, create a backwater. However, backwaters in these mobile gravel systems are, to a certain extent, temporary. The backwater created, ultimately, is intended to be planted in willows as an objective of GWRC's river management method. The enhanced habitat value is none the less a positive outcome of the work regardless of its temporary nature.

## 6.2. Applicability of findings to other rivers in the Wairarapa

All three rivers sampled in this study in relation to river management works undertaken by GWRC in 2012-2013 in the Wairarapa region are similar with respect to their physical characteristics: size, substrate composition, flow hydrology and periphyton, macroinvertebrate and fish communities. They appear to respond in a similar way to the small scale engineering works examined in the research.

The findings of this study are therefore able to be applied for consideration of the potential effects of other activities similar to these, elsewhere in gravel bed rivers and river reaches managed by GWRC within the Ruamahanga catchment, upstream of the Waiohine/Ruamahanga confluence.

## 6.3. Scale of Effects

Flood engineering works carried out in these Wairarapa rivers included in this study resulted in limited and short term (until the first fresh or flood) effects on in-stream communities and some minor changes in habitat (some positive, some negative). The works activities appear to be quite dramatic at the time (e.g., the very murky water in an otherwise crystal clear river) but the length of the effects of the activity are limited to resetting after the first fresh event. Thus they could be considered no more than that which occurs during most flood events. All of the study rivers experience frequent and often large floods that move channels and substrates quite dramatically and to which these organisms have adapted. The difficulty is that the normal cues, associated with flood events (rising water, substrate vibrations (Death, 2008)) are not present when the channel is worked by a bulldozer and not a flood. Thus the works do offer the potential to have deleterious effects on the biota, however all three studies in this report indicated little or no adverse effect. Only in the most severely engineered reach in the Waingawa were macroinvertebrate density and trout numbers not at pre-works level after the first fresh.

Deposited sediment increased following the works, because unlike a flood event where the suspended sediment is deposited along the length of the river, the generated sediment does not have the stream power to be pushed further than just downstream. But again the first fresh flushes it further down the river along with all the ‘natural’ flood sediment.

River engineering works such as channel realignment, bed recontouring and installation of rock groynes, on these 100 m stretches of river in isolation are unlikely to have long term adverse effects on the biological communities of the reaches involved.

The findings of these three surveys are likely to be applicable to other small scale river engineering works in other river segments in the Wairarapa where rivers experience frequent high discharge events and have comparatively low levels of fine sediment in the substrate.

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# APPENDICES

**Appendix A:** Mean density of invertebrates collected in 5 Surber samples (0.1m$^2$) at sites sampled on the Waingawa River in 2012.

| | MCI score | Pre Works | | | Post Works #1 | | | Post Works #2 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream |
| **Mayflies** | | | | | | | | | | |
| *Atalophlebiodes cromwelli* | 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| *Austroclima* sp. | 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.2 | 0.0 |
| *Deleatidium* sp. | 8 | 225.2 | 131.2 | 356.0 | 542.4 | 49.6 | 95.8 | 256.6 | 129.6 | 70.8 |
| *Neozephlebia scita* | 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Nesemaletus* sp. | 9 | 0.4 | 0.0 | 3.8 | 0.4 | 0.0 | 0.2 | 0.6 | 1.6 | 0.6 |
| **Stoneflies** | | | | | | | | | | |
| *Austroperla cyrene* | 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |
| *Stenoperla* sp. | 10 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Zelandobius* sp. | 5 | 0.0 | 0.4 | 1.0 | 0.2 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 |
| *Zelandoperla* sp. | 10 | 0.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| **Caddisflies** | | | | | | | | | | |
| *Aoteopsyche* sp. | 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 |
| *Beraeoptera roria* | 8 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.2 |
| *Hydrobiosis* sp. | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.6 | 1.8 | 0.0 |
| *Hydrobiosis clavigera* | 5 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| *Hydrobiosis frater* | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydrobiosidae (early instar) | 5 | 2.2 | 2.6 | 4.2 | 2.8 | 0.8 | 3.0 | 0.0 | 0.0 | 2.4 |
| *Hydrobiosis parumbripennis* | 5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Hydrobiosis umbripennis* | 5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydropsychidae (early instar) | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| *Olinga fereyadi* | 9 | 0.2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Plectronemia maclachlani* | 8 | 0.0 | 0.0 | 0.2 | 0.2 | 0.2 | 0.4 | 0.0 | 0.0 | 0.0 |
| *Psilochorema* sp. | 8 | 1.2 | 0.8 | 2.6 | 2.6 | 0.0 | 1.4 | 4.8 | 2.4 | 0.2 |
| *Pycnocentria* sp. | 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| *Pycnocentrodes* sp. | 5 | 0.0 | 0.0 | 2.8 | 0.0 | 0.0 | 2.4 | 0.2 | 0.2 | 0.0 |
| *Oxyethira albiceps* | 2 | 0.0 | 0.0 | 0.0 | 0.2 | 0.4 | 1.0 | 0.6 | 0.6 | 1.2 |
| **Beetles** | | | | | | | | | | |
| Elmidae | 6 | 4.6 | 2.0 | 16.4 | 12.0 | 0.2 | 7.6 | 16.4 | 3.2 | 6.8 |
| **Chironomidae** | | | | | | | | | | |
| Orthocladiinae | 2 | 1.2 | 1.0 | 7.8 | 7.2 | 5.8 | 18.4 | 4.8 | 2.2 | 1.0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tanypodinae | 5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| Tanytarsini | 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 |
| Chironomid pupae | 1 | 0.4 | 0.4 | 0.4 | 0.2 | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 |
| **Other Diptera** | | | | | | | | | | |
| Aphrophila | 5 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| Austrosimulium | 3 | 0.2 | 1.2 | 0.6 | 2.4 | 4.0 | 0.2 | 4.8 | 2.0 | 0.0 |
| Ceratopogonidae | 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| Empididae | 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| Eriopterini | 9 | 0.0 | 0.0 | 0.6 | 0.2 | 0.0 | 0.2 | 0.2 | 0.0 | 0.6 |
| **Mollusca** | | | | | | | | | | |
| *Potamopyrgus antipodarum* | 4 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| **Worms** | | | | | | | | | | |
| Oligochaetes | 1 | 0.2 | 0.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Other** | | | | | | | | | | |
| Acari | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| *Archichauliodes diversus* | 7 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| *Sigara* sp. | 5 | 0.0 | 0.6 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | | | |
| **Number of taxa** | | **5** | **7** | **9** | **7** | **4** | **9** | **8** | **7** | **7** |
| **Number of individuals** | | **236** | **141** | **399** | **572** | **62** | **132** | **295** | **144** | **85** |
| **% EPT (taxa)** | | **59** | **46** | **57** | **55** | **57** | **61** | **56** | **56** | **46** |
| **% EPT (individuals)** | | **97** | **94** | **93** | **96** | **83** | **78** | **90** | **94** | **85** |
| **MCI** | | **126** | **109** | **128** | **111** | **103** | **114** | **114** | **114** | **112** |
| **QMCI** | | **7.87** | **7.71** | **7.75** | **7.84** | **6.92** | **6.79** | **7.60** | **7.70** | **7.47** |

**Appendix B:** Mean density of invertebrates collected in 5 Surber samples ($0.1m^2$) at sites sampled on the Waiohine River in 2012.

| | MCI score | Pre Works | | | Post Works #1 | | | Post Works #2 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream |
| **Mayflies** | | | | | | | | | | |
| *Austroclima* sp. | 9 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Coloburiscus *humeralis* | 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 |
| *Deleatidium* sp. | 8 | 79.0 | 80.4 | 78.6 | 241.0 | 15.4 | 150.8 | 283.8 | 95.8 | 148.4 |
| *Nesemaletus* sp. | 9 | 0.8 | 0.2 | 2.4 | 1.0 | 0.0 | 0.8 | 1.0 | 0.0 | 0.4 |
| **Stoneflies** | | | | | | | | | | |
| *Stenoperla* sp. | 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| *Zelandobius* sp. | 5 | 0.0 | 0.6 | 0.0 | 0.4 | 0.0 | 1.3 | 0.4 | 0.0 | 0.8 |
| *Zelandoperla* sp. | 10 | 0.2 | 0.0 | 0.6 | 3.0 | 0.2 | 4.3 | 0.6 | 0.0 | 1.0 |
| **Caddisflies** | | | | | | | | | | |
| *Beraeoptera roria* | 8 | 0.0 | 0.2 | 0.0 | 5.4 | 0.0 | 0.3 | 1.8 | 0.4 | 0.6 |
| Costachorema callista | 7 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| *Helicopsyche* sp. | 10 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.8 | 0.2 | 0.0 | 0.0 |
| *Hydrobiosis clavigera* | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| Hydrobiosidae (early instar) | 5 | 0.0 | 0.2 | 0.4 | 2.4 | 0.2 | 1.5 | 3.4 | 0.8 | 1.4 |
| *Hydrobiosis parumbripennis* | 5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.4 |
| *Neurochorema* sp. | 6 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Olinga fereyadi* | 9 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.5 | 0.2 | 0.3 | 0.2 |
| *Plectronemia maclachlani* | 8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.2 |
| *Psilochorema* sp. | 8 | 0.2 | 2.4 | 1.6 | 1.2 | 0.0 | 2.5 | 2.8 | 0.4 | 6.4 |
| *Pycnocentria* sp. | 7 | 0.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |
| *Pycnocentrodes* sp. | 5 | 0.0 | 0.0 | 0.2 | 1.0 | 0.0 | 0.5 | 1.6 | 0.2 | 0.0 |
| *Oxyethira albiceps* | 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| **Beetles** | | | | | | | | | | |
| Elmidae | 6 | 0.8 | 0.0 | 0.0 | 0.8 | 0.0 | 2.3 | 2.6 | 0.6 | 3.8 |
| Hydraenidae | 8 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| **Chironomidae** | | | | | | | | | | |
| Maoridiamesa | 3 | 0.0 | 0.0 | 0.2 | 1.2 | 0.2 | 0.0 | 0.6 | 0.0 | 0.2 |
| Orthocladiinae | 2 | 20.0 | 1.4 | 6.2 | 19.2 | 0.8 | 8.3 | 23.4 | 0.8 | 17.0 |
| Tanypodinae | 5 | 0.0 | 0.2 | 0.0 | 0.4 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tanytarsini | 3 | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chironomid pupae | 1 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.3 | 2.0 | 0.2 | 0.6 |
| **Other Diptera** | | | | | | | | | | |
| Aphrophila | 0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.3 | 1.0 | 0.0 | 0.8 |
| Eriopterini | 9 | 0.2 | 0.6 | 0.8 | 0.2 | 0.0 | 1.0 | 1.8 | 0.8 | 1.0 |
| **Worms** | | | | | | | | | | |
| Oligochaetes | 1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.5 | 0.2 | 0.0 | 0.8 |
| **Other** | | | | | | | | | | |
| *Archichauliodes diversus* | 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.2 |
| | | | | | | | | | | |
| **Number of taxa** | | **4** | **5** | **5** | **10** | **2** | **11** | **11** | **4** | **9** |
| **Number of individuals** | | **101** | **87** | **91** | **285** | **17** | **177** | **328** | **100** | **185** |
| **% EPT (taxa)** | | **51** | **60** | **68** | **63** | **72** | **62** | **59** | **69** | **58** |
| **% EPT (individuals)** | | **81** | **97** | **89** | **91** | **95** | **93** | **91** | **98** | **86** |
| **MCI** | | **123** | **119** | **136** | **123** | **130** | **134** | **123** | **140** | **126** |
| **QMCI** | | **6.91** | **7.83** | **7.42** | **7.48** | **7.85** | **7.66** | **7.45** | **7.92** | **7.24** |

**Appendix C:** Mean density of invertebrates collected in 5 Surber samples ($0.1m^2$) at sites sampled on the Ruamahanga River in 2013.

| | MCI score | Pre Works | | | Post Works | | |
|---|---|---|---|---|---|---|---|
| | | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream |
| **Mayflies** | | | | | | | |
| *Atalophlebiodes cromwelli* | 9 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 |
| *Deleatidium* sp. | 8 | 177.0 | 58.2 | 0.6 | 69.8 | 19.6 | 36.0 |
| *Mauiulus luma* | 5 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 |
| *Nesemaletus* sp. | 9 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.8 |
| **Stoneflies** | | | | | | | |
| *Zelandobius* sp. | 5 | 0.0 | 0.0 | 0.0 | 0.8 | 0.2 | 5.4 |
| *Zelandoperla* sp. | 10 | 1.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Caddisflies** | | | | | | | |
| *Aoteopsyche* sp. | 4 | 57.6 | 8.6 | 0.4 | 2.8 | 0.6 | 4.8 |
| *Beraeoptera roria* | 8 | 0.0 | 0.0 | 0.2 | 0.8 | 0.6 | 33.8 |
| *Hudsonema amabilis* | 6 | 0.0 | 0.4 | 0.4 | 0.2 | 0.2 | 0.0 |
| *Hydrobiosis clavigera* | 5 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydrobiosidae (early instar) | 5 | 4.0 | 2.2 | 0.0 | 0.4 | 1.6 | 4.8 |
| *Hydrobiosis parumbripennis* | 5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| *Hydrobiosis umbripennis* | 5 | 0.0 | 0.2 | 0.0 | 0.0 | 0.2 | 0.2 |
| Hydropsychidae (early instar) | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 |
| *Olinga fereyadi* | 9 | 0.4 | 0.0 | 0.0 | 0.4 | 0.2 | 0.4 |
| *Orthopsyche* sp. | 9 | 0.0 | 0.0 | 0.0 | 0.4 | 0.8 | 2.0 |
| *Plectronemia maclachlani* | 8 | 0.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Psilochorema* sp. | 8 | 2.0 | 0.6 | 0.0 | 0.0 | 1.4 | 0.0 |
| *Pycnocentria* sp. | 7 | 0.6 | 3.8 | 8.6 | 0.8 | 0.2 | 12.4 |
| *Pycnocentrodes* sp. | 5 | 0.2 | 7.4 | 12.6 | 1.4 | 0.4 | 18.2 |
| *Oxyethira albiceps* | 2 | 0.0 | 0.2 | 0.6 | 0.0 | 0.0 | 0.4 |
| Caddis pupae | 5 | 0.2 | 0.2 | 1.2 | 0.0 | 0.0 | 0.6 |
| **Beetles** | | | | | | | |
| Elmidae | 6 | 7.0 | 34.6 | 41.2 | 5.6 | 1.0 | 24.8 |
| **Chironomidae** | | | | | | | |
| Orthocladiinae | 2 | 4.2 | 0.6 | 3.8 | 0.0 | 0.2 | 1.2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Tanypodinae | 5 | 0.6 | 1.6 | 3.0 | 0.0 | 0.0 | 0.0 |
| Tanytarsini | 3 | 4.2 | 110.0 | 148.2 | 0.2 | 0.4 | 5.6 |
| Chironomid pupae | 1 | 0.0 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 |
| **Other Diptera** | | | | | | | |
| Austrosimulium | 3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.2 | 0.4 |
| Eriopterini | 9 | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 3.0 |
| Molophilus | 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| Sciomyzidae | 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| **Crustacea** | | | | | | | |
| Paracalliope | | 0.2 | 0.6 | 1.4 | 0.4 | 0.2 | 0.0 |
| Ostracoda | 3 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Mollusca** | | | | | | | |
| Limpit | | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| *Physa* sp. | 3 | 0.0 | 0.2 | 4.0 | 0.2 | 0.0 | 0.2 |
| *Potamopyrgus antipodarum* | 4 | 1.0 | 7.8 | 24.4 | 0.2 | 0.0 | 15.4 |
| **Worms** | | | | | | | |
| Horse-hair Worm | 3 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| Nemertea | 3 | 0.2 | 1.4 | 1.8 | 0.0 | 0.0 | 0.4 |
| Oligochaetes | 1 | 0.0 | 0.0 | 8.8 | 0.2 | 1.0 | 5.4 |
| Platyhelminthes | 3 | 0.0 | 2.4 | 2.4 | 0.0 | 0.0 | 1.4 |
| **Other** | | | | | | | |
| Acari | 5 | 0.2 | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 |
| *Archichauliodes diversus* | 7 | 0.6 | 0.8 | 0.2 | 0.4 | 0.0 | 0.4 |
| Odonata | 5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| *Sigara* sp. | 5 | 0.2 | 0.8 | 6.4 | 0.0 | 0.0 | 0.0 |
| | | | | | | | |
| **Number of taxa** | | **11** | **14** | **15** | **7** | **7** | **18** |
| **Number of individuals** | | **264** | **246** | **274** | **85** | **29** | **184** |
| **% EPT (taxa)** | | **51** | **41** | **25** | **69** | **67** | **53** |
| **% EPT (individuals)** | | **92** | **27** | **10** | **93** | **89** | **67** |
| **MCI** | | **119** | **107** | **91** | **118** | **115** | **107** |
| **QMCI** | | **6.98** | **4.59** | **3.93** | **7.56** | **7.21** | **6.18** |

**Appendix D:** Number of fish species collected at sites sampled on the Waingawa River in 2012.

| | Pre Works | | | Post Works #1 | | | Post Works #2 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream |
| **Upland Bullies** | 5 | 14 | 1 | 2 | 0 | 1 | 1 | 4 | 6 |
| **Common Bullies** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Bluegill Bullies** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| **Bullies (Unidentified)** | 4 | 9 | 18 | 0 | 3 | 0 | 0 | 0 | 1 |
| **Torrent fish** | 8 | 2 | 3 | 5 | 3 | 0 | 7 | 1 | 0 |
| **Trout** | 2 | 1 | 7 | 2 | 0 | 1 | 2 | 0 | 0 |
| **Longfin eels** | 1 | 0 | 0 | 3 | 2 | 0 | 5 | 0 | 0 |
| **Shortfin eels** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Eels (Unidentified)** | 4 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| **Elvers** | 1 | 0 | 3 | 0 | 0 | 3 | 3 | 9 | 0 |
| | | | | | | | | | |
| **Total No. of Fish** | **25** | **26** | **32** | **15** | **8** | **5** | **18** | **18** | **8** |
| **Total No. of Species** | **4** | **3** | **4** | **4** | **3** | **3** | **4** | **3** | **1** |

**Appendix E:** Number of fish species collected at sites sampled on the Waiohine River in 2012.

| | Pre Works | | | Post Works #1 | | | Post Works #2 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream |
| **Upland Bullies** | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 3 |
| **Common Bullies** | 95 | 16 | 53 | 33 | 4 | 17 | 15 | 1 | 9 |
| **Redfin Bullies** | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Bullies (Unidentified)** | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 |
| **Torrent fish** | 3 | 0 | 0 | 4 | 0 | 12 | 2 | 0 | 3 |
| **Trout** | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| **Longfin eels** | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Shortfin eels** | | | | | | | | | |
| **Eels (Unidentified)** | 0 | 0 | 0 | 1 | 0 | 0 | 9 | 0 | 0 |
| **Elvers** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | | | | | | | |
| **Total No. of Fish** | **101** | **16** | **54** | **38** | **4** | **29** | **44** | **1** | **19** |
| **Total No. of Species** | **3** | **1** | **2** | **3** | **1** | **2** | **4** | **1** | **4** |

**Appendix F:** Number of fish species collected at sites sampled on the Ruamahanga River in 2013.

| | Pre Works | | | Post Works | | |
|---|---|---|---|---|---|---|
| | Upstream | Works Area | Downstream | Upstream | Works Area | Downstream |
| **Upland Bullies** | 0 | 0 | 0 | 10 | 6 | 24 |
| **Common Bullies** | 1 | 0 | 0 | 0 | 1 | 7 |
| **Redfin Bullies** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bullies (Unidentified)** | 13 | 16 | 20 | 0 | 0 | 0 |
| **Torrent fish** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Trout** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Longfin eels** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Shortfin eels** | 0 | 1 | 0 | 0 | 0 | 0 |
| **Eels (Unidentified)** | 1 | 0 | 0 | 1 | 0 | 0 |
| **Elvers** | 0 | 0 | 2 | 3 | 0 | 0 |
| **School of fish (Unidentified)** | 12 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | |
| **Total No. of Fish** | **27** | **17** | **22** | **14** | **7** | **31** |
| **Total No. of Species** | **3** | **2** | **2** | **2** | **1** | **1** |