Kā Pūtahi/Kaputone Creek Realignment: Year One Aquatic Ecology Survey

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(updated May 2018)

AQUATIC SCIENCE &
VISUAL COMMUNICATION

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EXECUTIVE SUMMARY

To avoid the installation of two long culverts in Kā Pūtahi (Kaputone Creek) as part of building the Northern Arterial Motorway (NArt), Christchurch City Council (CCC) rerouted the stream via the construction of a ~350 m long realignment channel. The realignment channel was intended to include a range of physical habitat features that would provide an enhanced instream environment compared to the original Kā Pūtahi channel, which has been degraded by rural and urban land use. Following a baseline survey undertaken in April 2016 by Boffa Miskell prior to livening of the realignment, EOS Ecology was contracted to undertake a "Year One" survey of habitat, freshwater macroinvertebrates, and fish in January-February 2017 to assess the ecological state of the realignment early in the successional process. The ultimate long-term purpose of this survey and subsequent monitoring is to assess the successional changes in the stream at the location of the realignment, and to determine whether the instream works have increased ecological values within Kā Pūtahi.

The habitat of the realigned section differs from that of the original channel predominantly by having a hard stony streambed and a lack of any tall riparian vegetation to shade the channel. Faster flowing riffle sections in the realignment section are limited in extent such that overall the water velocities of the realignment section are not very different to the very low velocities of the original channel. It is likely such conditions will result in the stony constructed streambed of the realignment channel progressively being covered in fine sediments.

The differences in habitat and early stage of succession have resulted in the realignment section having macroinvertebrate and fish assemblages distinct from those of the original (control) channel. Primarily the higher densities of the endemic snail *Potamopyrgus antipodarum* at the control sites and the higher densities of the exotic snail *Physa acuta*, Orthocladiinae midge larvae, and *Sigara* water boatmen at the realignment sites drive the macroinvertebrate community differences. Also notable was the presence of several caddisfly taxa at the realignment sites, which were absent from the control sites. While these were in very low densities, it was encouraging to see these taxa colonising suitable stony streambed habitat so soon after construction. For fish, high densities of the common bully at the realignment sites and of shortfin eels at the control sites were the main fish community differences. The realignment section had limited cover for larger bodied fish, in particular eels.

Given this survey was undertaken so soon after construction, the realignment section was in a stage of early succession and colonisation such that it is premature to make any definitive statements on whether the realignment works have improved the ecological values of this part of Kā Pūtahi. Additionally, it must be remembered that the pervasive negative ecological effects of upstream rural and urban land uses place constraints on what ecological values may indeed be improved through physical habitat modification of a relatively short length of stream.

Recommendations include making various modifications to the stream channel to improve physical habitat (especially rectifying riffle zones that lack surface water flow at low flows, increased fish cover and more riffle habitat with faster water velocities), developing some realistic and measureable ecological goals for the project to help guide further monitoring, and allowing sufficient time for successional processes to occur before undertaking further monitoring. At the time of writing, CCC ecologists and engineers were evaluating options for further enhancing physical habitat along the realignment, with the intention of carrying out physical works in 2017 (Dr Greg Burrell, CCC, pers. comm.).

1 INTRODUCTION

In the first quarter of 2016, Christchurch City Council (CCC) constructed an approximate 350 m long new section of channel in Kā Pūtahi/Kaputone Creek[1]. This was undertaken to avoid the construction of two long box culverts in Kā Pūtahi as part of the Northern Arterial (NArt) Motorway project and resulted in the cutting off of a sharply curved section of original Kā Pūtahi channel (referred to as the "oxbow"). The design of the realigned channel was modelled on that of the Kaituna River, which originates on Bank Peninsula and flows into Lake Ellesmere/Te Waihora. The intent was to include a range of meso-habitats including pool-run-riffles sequences, low *Carex* sedge floodplains, steep reinforced banks, submerged logs, boulders, tree stump and root ball overhangs, and a diversity of bank profiles (Shadbolt, 2015).

Shadbolt (2015) states the overall vision of the project as: "The realignment and naturalisation of Kaputone Creek sees the long-term ecological viability of this important natural waterway protected for future generations to enjoy and benefit from. Within the new stream corridor, more than 2.5 ha of planted podocarp forest will link seamlessly with stream restoration initiatives up and down stream to provide both an aquatic and terrestrial ecological network across the catchment, and also a core forest patch in its own right. Here the forested waterway will abound with native birds, insects and fish, and people will visit to enjoy this restored environment on a daily basis, to be with nature and to co-manage and utilise traditional cultural resources provided by the site."

In April 2016 a baseline ecological survey of Kā Pūtahi prior to livening of the new channel was undertaken by Boffa Miskell with the aim of describing the existing riparian and in-stream physical habitat conditions and macroinvertebrate and fish communities at defined sites along Kā Pūtahi (Boffa Miskell, 2016). The intent was for this baseline data to be used as a comparison with subsequent monitoring data once the new channel was operating. EOS Ecology was engaged to undertake the "Year One" realignment monitoring in the summer of 2017. The long-term purpose of this monitoring is to assess the successional changes in the stream at the location of the realignment and to determine whether the instream works have increased ecological values within Kā Pūtahi.

2 METHODS

2.1 Site Selection

Prior to fieldwork a site visit with Dr Greg Burrell (CCC) was undertaken to discuss the survey design and select survey sites. Because the new channel was operational at this time, and thus the "oxbow" section of original channel was no longer receiving the main flow of Kā Pūtahi, some of the sites selected were different to those of the Boffa Miskell baseline survey. Three sites were selected within the realignment section (R1, R2, and R3) while the baseline sites upstream and downstream of the realignment were designated as "control" sites (C1 and C2 (Sites 1 and 4 in Boffa Miskell (2016)) (Figure 1, Table 1). The two "oxbow" sites from the baseline survey (Sites 2 and 3 in Boffa Miskell (2016)) were not resurveyed on account of this section of Kā Pūtahi having been dewatered and fish removal actions having occurred. The baseline survey sites were also renamed to better account for their status as "control" sites (Table 1). Fieldwork was completed between 25 January and 9 February 2017 during a period of base flow (Table 2). Site photos are shown in Appendix 9.1.

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[1] Kā Pūtahi has been accepted as the correct spelling for the waterway that is commonly referred to as Kaputone Creek, and thus will be the name used in this report.

Figure 1 Locations of the five “Year One” sites in Kā Pūtahi surveyed by EOS Ecology in January–February 2017.

Table 1 Site codes, location, and co-ordinates (NZTM) for the five "Year One" survey sites and the Boffa Miskell (2016) baseline survey sites.

Year One Survey Site Codes	Baseline Survey Site Number	Location	Upstream Extent		Downstream Extent	
			Easting (NZTM)	Northing (NZTM)	Easting (NZTM)	Northing (NZTM)
C1	Site 1	Upstream of realignment (control site)	1570704	5187873	1570735	5187915
C2	Site 4	Downstream of realignment (control site)	1570954	5188546	1570998	5188513
R1	Not surveyed	Realignment upper site	1570823	5188080	1570849	5188091
R2	Not surveyed	Realignment mid site	1570919	5188249	1570938	5188275
R3	Not surveyed	Realignment lower site	1570981	5188333	1571002	5188377
Not surveyed (designated O1 for analysis)	Site 2	Upstream oxbow	1571095	5188093	1571147	5188081
Not surveyed (designated O2 for analysis)	Site 3	Downstream oxbow	1571125	5188228	1571085	5188255

Table 2 Sampling dates for the five "Year One" survey sites.

Year One Survey Site Codes	Habitat Survey and Macroinvertebrate Sampling	Passive Fish Sampling (fyke nets and Gee minnow traps)	Active Fish Sampling (electrofishing)
C1	31 January 2017	1 February 2017	9 February 2017
C2	30 January 2017	1 February 2017	9 February 2017
R1	26 January 2017	31 January 2017	27 January 2017
R2	25 January 2017	31 January 2017	27 January 2017
R3	25 January 2017	31 January 2017	26 January 2017

2.2 Sampling

2.2.1 Habitat and Water Quality

Riparian and in-stream habitat assessment followed the same methodology as the baseline study (Boffa Miskell, 2016). This followed Protocol 3 (P3) of Harding *et al.* (2009) for general quantification of habitat that included:

- P3b: In-stream hydrological and morphological assessment
- P3c: In-stream physical habitat assessment
- P3d: Riparian habitat assessment.

Two sediment assessment methods (SAM) of Clapcott *et al.* (2011) were used to measure deposited fine sediment:

- SAM 2: In-stream visual estimate of % sediment cover
- SAM 6: Sediment depth

The Harding *et al.* (2009) and Clapcott *et al.* (2011) protocols are freely available to anyone online and include full descriptions of the methodologies as well as field record sheet templates. As with the baseline survey, each survey site was 50 m long with six transects at 10 m intervals. Harding *et al.* (2009) requires the six cross-sections to be spread across two riffles, two runs, and two pools. Sites C1, C2, and R3 had only run habitat hence all transects were in this meso-habitat. At each of Site R1 and R2 transect meso-habitat distribution was: one in a riffle, one in a pool, and four in runs. It should be noted that in the realignment there was not a lot of difference between the slow run habitat and pool habitat such that a precise distinction was not always possible. Comprehensive photos of each site were also taken.

Spot measures of water temperature, pH, specific conductivity, and dissolved oxygen were taken at each site using calibrated, handheld meters (dissolved oxygen and temperature: YSI ProODO; conductivity: Eutech TDScan 3; pH: Eutech pHTestr 30).

2.2.2 Macroinvertebrates

Five replicate Surber samples (0.1 m^2; 500 m mesh) were taken from within each of the five sites following Protocol C3 of Stark *et al.* (2001). These were taken from locations chosen to be representative of the surrounding habitat and typically within 1.5 m of each transect line (with no sample at the 0 m transect). Samples were preserved in 90% iso-propyl alcohol (IPA) and processed at EOS Ecology following the protocol P3 of Stark *et al.* (2001). To ensure consistency with the baseline data, macroinvertebrates were identified to the same taxonomic level as the baseline survey (Boffa Miskell, 2016).

2.2.3 Fish

At each of the five sites, the primary method of fish sampling was electrofishing of the same 50 m reach as where the habitat and macroinvertebrate sampling was undertaken. This generally followed the single-pass methodology of Joy *et al.* (2013) and used a NIWA Kainga EFM300 electrofishing machine (Figure 2). For consistency with the baseline survey, which did not include electrofishing, two fyke nets and five Gee minnow traps (GMT) were deployed in each survey reach for a single night. The fyke nets were of the fine-mesh with eel exclusion chamber design of Joy *et al.* (2013), which were also used in the baseline survey (Dr Tanya Blakely, Boffa Miskell, pers. comm.) (Figure 2). The GMTs used had a mesh size of 3.2 mm. All nets and traps were baited with burley pellets. All fish captured in nets and traps or via electrofishing were identified and their length measured before being released back to Kā Pūtahi (Figure 2).

Setting a Gee minnow trap

Setting a fyke net

Electrofishing

Fish identification

Figure 2 Fish sampling in the realignment section of Kā Pūtahi.

2.3 Data Analysis

2.3.1 Habitat

Habitat parameters were generally summarised as means and standard errors. For selected habitat parameters, the coefficient of variation was calculated (CV=standard deviation/mean) to compare habitat variability/heterogeneity between the control and realignment sites. One way and two way analysis of variance (ANOVA) was used to investigate differences between sites and surveys. Details of ANOVA are fully described in Section 2.3.3. Cross sections of each transect as required by CCC were prepared in SigmaPlot 12.5 (see Appendix 9.3)

2.3.2 Macroinvertebrates

Invertebrate data were summarised by taxa richness, total abundance, abundance of the five most common taxa, and non-metric multidimensional scaling ordination (NMS). Biotic indices calculated were the number of Ephemeroptera-Plecoptera-Trichoptera taxa (EPT taxa richness), %EPT abundance, and the Macroinvertebrate Community Index (MCI and QMCI). The points below provide brief clarification of these metrics.

- Taxa richness is the number of different taxa identified in each sample. Taxa is generally a term for taxonomic groups, and in this case refers to the lowest level of classification that was obtained during the study. Taxa richness is a useful community metric related to habitat diversity, with sites with more diverse habitats often having greater richness. However, there are numerous aquatic invertebrate taxa that prefer or tolerate degraded instream conditions such that taxa richness on its own should not be used to infer stream health. In the context of this report where a new “improved” realignment section of stream is being compared to control sites, more importance can be ascribed to taxa richness.
- EPT refers to three Orders of invertebrates that are generally regarded as ‘cleanwater’ taxa. These Orders

are Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies); forming the acronym EPT. These taxa are relatively intolerant of organic enrichment or other pollutants and habitat degradation. The exceptions to this are the hydroptilid caddisflies (e.g. Trichoptera: Hydroptilidae: *Oxyethira, Paroxyethira*), which are algal piercers and often found in high numbers in nutrient enriched waters with high algal content. For this reason, EPT metrics are presented with and without these taxa. EPT taxa richness and %EPT abundance can provide a good indication as to the health of a particular site. The disappearance and reappearance of EPT taxa also provides evidence of whether a site is impacted or recovering from a disturbance, or in the context of this report, if newly created habitat has been colonised by such taxa. EPT taxa are generally diverse in non-impacted, non-urbanised stream systems, although there is a small set of EPT taxa that are also found in urbanised waterways.

- In the mid-1980s the MCI was developed as an index of community integrity for use in stony riffles in New Zealand streams and rivers, and can be used to determine the level of organic enrichment for these types of streams (Stark, 1985). Although developed to assess nutrient enrichment, the MCI will respond to any disturbance that alters macroinvertebrate community composition (Boothroyd & Stark, 2000), and as such is used widely to evaluate the general health of waterways in New Zealand. Recently a variant for use in streams with a streambed of sand/silt/mud (i.e. soft-bottomed) was developed by Stark & Maxted (2007a) and is referred to as the MCI-sb. Both the hard-bottomed (MCI-hb) and soft-bottomed (MCI-sb) versions calculate an overall score for each sample, which is based on pollution-tolerance values for each invertebrate taxon that range from 1 (very pollution tolerant) to 10 (pollution-sensitive). MCI-hb and MCI-sb are calculated using presence/absence data and a quantitative version has been developed that incorporates abundance data and so gives a more accurate result by differentiating rare taxa from abundant taxa (QMCI-hb, QMCI-sb). MCI (QMCI) scores of ≥120 (≥6.00) are interpreted as 'excellent', 100–119 (5.00–5.99) as 'good', 80–99 (4.00–4.99) as 'fair', and <80 (<4.00) as 'poor' (Stark & Maxted, 2007b). The soft-bottomed variant was used at the two control sites (C1 and C2) where the dominant substrate size was fine (soft) and the hard-bottomed variant at the three realignment sites (R1, R2, and R3) where the substrate was predominantly stony.
- NMS is non-metric statistical technique that condenses sample data (in this case macroinvertebrate community data) to a single point in low-dimensional ordination space using some measure of community dissimilarity (Bray-Curtis metric in this instance). Interpretation is straightforward such that points on an x-y plot that are close together represent samples that are more similar in community composition than those further apart (Clarke & Gorley, 2006). Significant differences in macroinvertebrate community composition between sites were tested using the analysis of similarities (ANOSIM) procedure, which is a non-parametric procedure, applied to the similarity matrix that underlies the NMS ordination. ANOSIM is an approximate analogue of the standard ANOVA (analysis of variance) and compares the similarity between groups (in this instance control and realignment) using the R test statistic. R=0 where there is no difference in macroinvertebrate community between groups, while R=1 where there groups have completely different communities. Where ANOSIM results showed significant or near-significant differences in macroinvertebrate community compositions, the similarity percentages (SIMPER) procedure was used to determine which taxa where responsible. NMS, ANOSIM, and SIMPER were all carried out in PRIMER v6.1.5 (Clarke & Gorley, 2006).

2.3.3 Analysis of Variance

One-way analysis of variance (ANOVA) was used to investigate differences in habitat attributes and aquatic macroinvertebrate community metrics between the five sites in 2017. Where there were multiple measures across a transect, these were averaged prior to ANOVA such that each transect was a replicate. Data transformations were used (e.g. log10), where necessary, to fulfil the requirements of the parametric tests (i.e., equal variance and normality). The level of significance was set at p=0.05. Where significant differences were observed, the *post-hoc* Holm-Sidak test was used to identify site means that were significantly different. Where the requirements of the parametric tests (i.e. equal variance and normality) could not be achieved with data transformation, the non-parametric Kruskal-Wallis test was used along with the *post hoc* Tukey test where significantly different site medians were observed.

In addition, two-way ANOVAs – with site and time as main factors – were used to investigate differences in aquatic macroinvertebrate community metrics and habitat attributes between the control sites (Sites C1 and C2) and years (baseline survey: 2016 and year one survey: 2017). The realignment sites obviously did not exist during the baseline survey, hence were not included in any two-way ANOVA. All ANOVAs were carried out in SigmaPlot 12.5.

2.3.4 Fish

All fish data was converted to catch per unit effort (CPUE), which is a measure of the number of individuals caught for a given level of effort. For the "Year One" electrofishing survey data CPUE was expressed as the number of fish caught per 1 m^2 fished. For the GMT and fyke net data CPUE was expressed as fish/net/night as recommended by Joy *et al.* (2013). Site species richness was calculated for both electrofishing and GMT/fyke net data. Fish community data from the "Year One" survey collected via electrofishing was compared among sites using NMS (see Section 2.3.2 for a full description of this technique).

3 RESULTS

3.1 Habitat

Spot measures of physicochemical parameters indicated generally higher water temperatures during the "Year One" survey, which was likely a result of the time of year (April for baseline survey and late-January–early-February for "Year One" survey). In both surveys pH was circumneutral to slightly alkaline and the water relatively well oxygenated (Table 3). However, spot measures of such parameters that vary on diurnal (and seasonal) cycles cannot be used to characterise habitat condition or necessarily infer stress on biota.

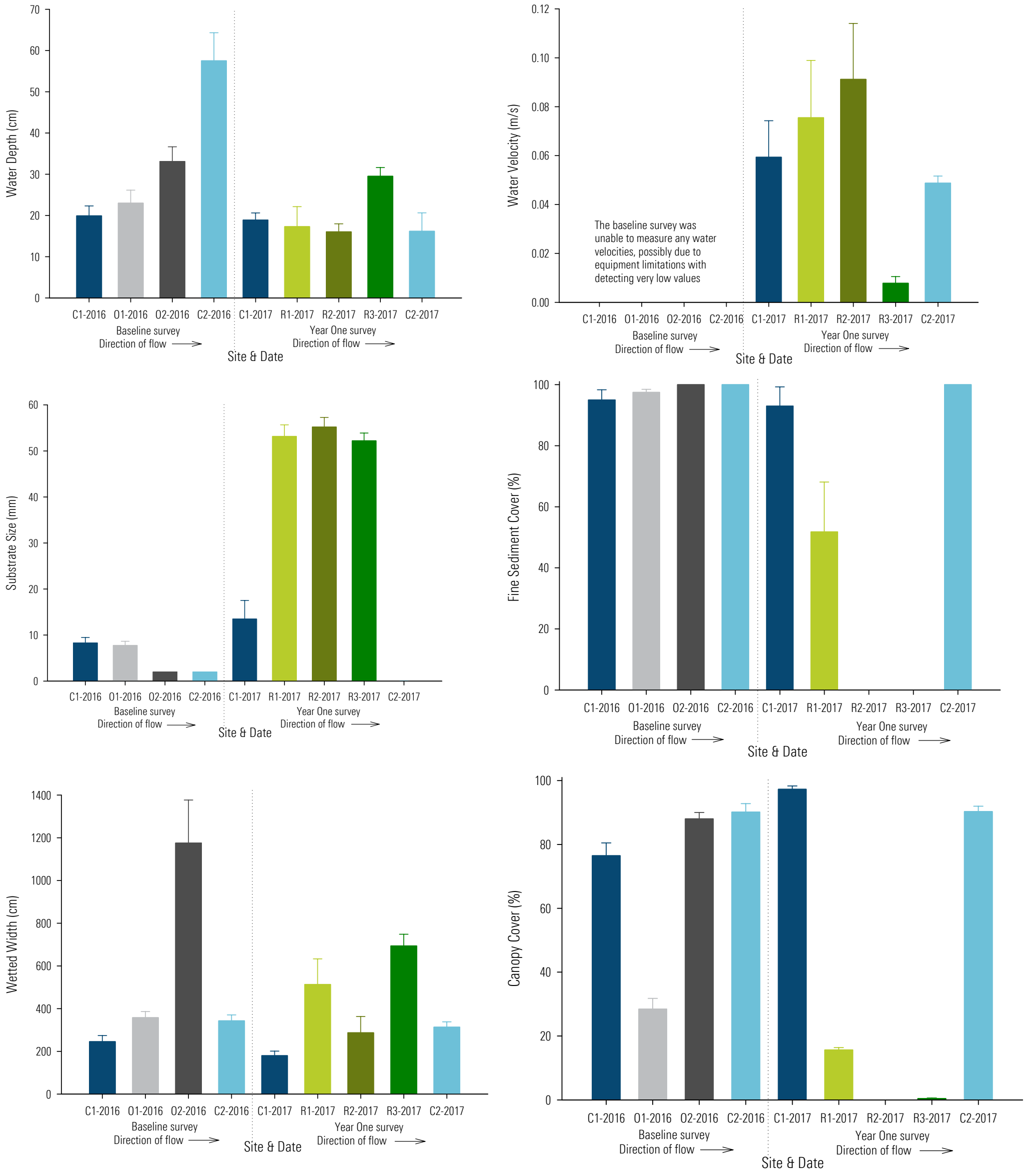
The realignment sites have more diversity of meso-habitat, although in practice the runs generally had very low velocities such that there was little distinguishing them from pool habitat. A comparison of key habitat variables among sites during the "Year One" survey found there were significant site differences among water depth, water velocity, wetted width, substrate size, fine sediment cover, and canopy cover (Table 3, Figure 3, Table 4). Additionally, some realignment riffle sections lacked surface flow over the summer period. Notable habitat differences that could affect the composition of freshwater biota were water velocity being higher at the R1 and R2 realignment sites than at the R3 site with the two control sites being intermediate; the significantly larger substrate size (and less cover of fine sediment) of the three realignment sites; and the generally greater canopy cover of the control sites (Table 3, Figure 3, Table 4). The control sites were predominantly soft-bottomed with greater soft sediment cover and depths (and smaller substrate size) than the realignment sites (Table 3, Figure 3). Macrophytes were most prevalent (albeit patchy) at the R1 site, while algae was much more prominent at the three realignment sites, at least partially resulting from the high light availability due to the minimal canopy cover at those sites (Table 3).

Table 3 Mean values of various habitat parameters recorded at Kā Pūtahi sites from the baseline and "Year One" surveys. Standard errors are shown in parentheses. Water temperature, pH, conductivity, dissolved oxygen, and meso-habitat length are single values. Baseline data was collected by Boffa Miskell (2016) and the "Year One" data by EOS Ecology. Note that only the C1 and C2 control sites were sampled during both surveys. Neg = negligible flow noted in baseline survey.

	Baseline Survey: April 2016				Year One Survey: January–February 2017				
Parameter	**C1 (Site 1)**	**O2 (Site 2)**	**O3 (Site 3)**	**C2 (Site 4)**	**C1**	**R1**	**R2**	**R3**	**C2**
Water temperature (°C)	11.1	12.0	10.7	13.2	18.5	13.6	22.3	17.8	15.5
pH	7.83	7.62	7.45	7.86	8.21	7.63	7.80	7.80	7.95
Conductivity (µS/cm)	189	214	210	221	190	258	296	296	208
Dissolved oxygen (mg/L)	8.24	9.39	8.10	6.52	9.35	7.63	11.63	8.13	8.58
Dissolved oxygen (%)	No data	No data	No data	No data	99	73	134	86	86
Meso-habitat length (m)	Run: 50	Run: 50	Run: 50	Run: 50	Run: 50	Run: 22 Riffle: 6 Pool: 22	Run: 38 Riffle: 6 Pool: 6	Run: 50	Run: 50
Water velocity (m/s)	Neg	Neg	Neg	Neg	0.06 (0.01)	0.08 (0.02)	0.09 (0.02)	0.01 (0)	0.05 (0)
Water depth (cm)	20 (2)	23 (3)	33 (4)	58 (7)	19 (2)	17 (5)	16 (2)	30 (2)	16 (4)
Wetted width (m)	2.45 (0.29)	3.58 (0.28)	11.75 (2.01)	3.43 (0.28)	1.80 (0.21)	5.13 (1.20)	2.87 (0.76)	6.94 (0.55)	3.13 (0.25)
Substrate size (mm)	8.3 (1.2)	7.8 (0.9)	2 (0)	2 (0)	13.5 (4)	53.2 (2.5)	55.2 (2.1)	52.2 (1.7)	0.06 (0)
Embeddedness[1]	3.9 (0.07)	3.9 (0.07)	4 (0)	4 (0)	3.3 (0.2)	1.9 (0.2)	1.0 (0)	1.0 (0)	4.0 (0)
Compactness[2]	4 (0)	4 (0)	4 (0)	4 (0)	3.7 (0.2)	1.3 (0)	1.0 (0)	1.0 (0)	4.0 (0)
Soft sediment depth (cm)	8 (2)	35 (5)	96 (13)	35 (2)	6 (2)	1 (0)	0 (0)	0 (0)	42 (2)
Soft sediment cover (%)	95 (3)	98 (1)	100 (0)	100 (0)	93 (6)	51 (16)	0 (0)	0 (0)	100 (0)
Macrophytes (cm)	3 (1.7)	3 (1.1)	58 (50.5)	0 (0)	35 (24)	121 (88)	18 (18)	0 (0)	8 (7)
Algae (cm)	5 (3)	21 (16)	64 (42)	0 (0)	0 (0)	80 (46)	225 (77)	693 (54)	10 (8)
Leaf packs (cm)	6 (2.4)	6 (0.8)	719 (253)	32 (15)	5 (3)	33 (33)	3 (3)	0 (0)	0 (0)
Woody debris (cm)	22 (7.7)	4 (0.5)	163 (42)	33 (15)	23 (5)	25 (11)	2 (2)	0 (0)	116 (44)
Large boulder and wood jams (count)	0.3 (0.2)	0.3 (0.2)	12.8 (0.7)	2.5 (1.6)	0 (0)	1 (0)	0.5 (0.5)	0 (0)	0 (0)
Overhanging vegetation (cm)	13 (4)	11 (7)	0 (0)	8 (4)	10 (8)	0 (0)	0 (0)	0 (0)	15 (4)
Canopy cover (%)	76.5 (4)	28.4 (3.3)	88 (2)	90.2 (2.6)	97.3 (1)	15.7 (0.7)	0 (0)	0.4 (0.2)	89.9 (1.7)

[1] Embeddedness was assessed on a four point scale: 1 = not embedded; 2 = slightly embedded; 3 = firmly embedded; 4 = heavily embedded.

[2] Compactness was assessed on a four point scale: 1 = loose; 2 = mostly loose; 3 = moderately packed; 4 = tightly packed.



The baseline survey was unable to measure any water velocities, possibly due to equipment limitations with detecting very low values

Figure 3 Means of key habitat parameters (+1 S.E.) from Kā Pūtahi sites from the baseline and "Year One" surveys. Baseline data was collected by Boffa Miskell (2016) and the "Year One" data by EOS Ecology in 2017. Note that only the C1 and C2 control sites were sampled during both surveys.

Table 4 Results of the one-way analysis of variance (ANOVA) of key habitat parameters from the 2017 "Year One" survey. The Holm-Sidak *post-hoc* test (ANOVA) or Tukey test (Kruskal-Wallis) was used to find which site means (or medians) were significantly different. n/s = not significant; n/a = not applicable. Sites listed in descending order of means (or medians). For comparisons among means (or medians) the letters denote where there are differences (i.e., means or medians denoted with the same letter are not statistically different).

Habitat Parameter	ANOVA Result	Significant Site Differences
Water depth	$F_{4, 25} = 2.9, p = 0.041$	R3: C1: R2: R1: C2 too weak to detect
Water velocity	$H = 15.22, p = 0.004$	R2: R1: C2: C1: R3 a a ab ab b
Substrate size	$F_{4, 25} = 114.25, p < 0.001$	R2: R1: R3: C1: C2 a a a b c
Fine sediment cover	$H = 22.68, p < 0.001$	C1: C2: R1: R2: R3 a a ab b b
Wetted width	$F_{4, 25} = 10.09, p < 0.001$	R3: R1: C2: R2: C1 a ab bc bc c
Canopy cover	$H = 91.01, p < 0.001$	C1: C2: R1: R2: R3 a ab b c c

The riparian vegetation of the control sites and the oxbow sites typically had greater representation across the five height categories than the realignment sites (Table 5). The realignment sites had no vegetation above the 0.3–1.9 m height class, which is of no surprise given all vegetation in this section has been planted in the last year (Table 5). Of the control and oxbow sites only the true-left bank of the C1 site had a substantial buffer width in which riparian vegetation has established. In contrast the realignment sites have mean buffer widths of between 13.5–60+ m, which will allow the development of substantial vegetated riparian zone over time (Table 5).

Table 5 Mean percentage cover of riparian vegetation at four distances from each bank edge from the baseline and “Year One” surveys. The vegetation tier height with the greatest percentage cover is highlighted in bold. The mean buffer widths are also shown for each site and bank.

Site	Bank	Distance from Bank	Vegetation Tier Heights				
			0–0.3 m	0.3–1.9 m	2–4.9 m	5–12 m	>12 m
C1-2016	TLB (Mean buffer width = 28.4 m)	0.5 m	19	29	**38**	14	0
		3 m	12	28	**42**	18	0
		7.5 m	10	30	**41**	19	0
		20 m	10	28	**39**	23	0
	TRB (Mean buffer width = 8.4 m)	0.5 m	**66**	12	3	19	0
		3 m	**54**	37	7	2	0
		7.5 m	**56**	36	4	4	0
		20 m	**50**	32	0	0	0
O1-2016	TLB (Mean buffer width = 2.5 m)	0.5 m	**48**	16	18	18	0
		3 m	**48**	14	14	24	0
		7.5 m	**56**	22	12	10	0
		20 m	**100**	0	0	0	0
	TRB (Mean buffer width = 0 m)	0.5 m	**100**	0	0	0	0
		3 m	**100**	0	0	0	0
		7.5 m	**100**	0	0	0	0
		20 m	**50**	25	25	0	0
O2-2016	TLB (Mean buffer width = 1 m)	0.5 m	19	21	**45**	15	20
		3 m	**68**	0	10	2	0
		7.5 m	**100**	0	0	0	0
		20 m	**100**	0	0	0	0
	TRB (Mean buffer width = 1 m)	0.5 m	**56**	0	8	36	0
		3 m	**100**	0	0	0	0
		7.5 m	**100**	0	0	0	0
		20 m	**100**	0	0	0	0
C2-2016	TLB (Mean buffer width = 1 m)	0.5 m	**50**	16.7	0	33.3	0
		3 m	**100**	0	0	0	0
		7.5 m	**98**	2	0	0	0
		20 m	**96**	4	0	0	0
	TRB (Mean buffer width = 0.6 m)	0.5 m	**68**	12	0	20	0
		3 m	**90**	10	0	0	0
		7.5 m	**96**	4	0	0	0
		20 m	**100**	0	0	0	0

Table 5 continued.

Site	Bank	Distance from Bank	Vegetation Tier Heights				
			0–0.3 m	0.3–1.9 m	2–4.9 m	5–12 m	>12 m
C1-2017	TLB (Mean buffer width = 60 m)	0.5 m	**20**	**20**	**20**	**20**	16
		3 m	**20**	**20**	**20**	**20**	**20**
		7.5 m	**20**	**20**	**20**	**20**	**20**
		20 m	**20**	**20**	**20**	**20**	**20**
	TRB (Mean buffer width = 4.8 m)	0.5 m	**40**	26	4	12	18
		3 m	**50**	26	8	8	8
		7.5 m	**42**	12	6	0	0
		20 m	**48**	6	6	0	0
C2-2017	TLB (Mean buffer width = 1.1 m)	0.5 m	26	1	2	19	**52**
		3 m	38	0	0	19	**43**
		7.5 m	**66**	4	0	0	20
		20 m	**90**	10	0	0	0
	TRB (Mean buffer width = 0.7 m)	0.5 m	16	0	0	0	**84**
		3 m	**85**	0	0	0	15
		7.5 m	**100**	0	0	0	0
		20 m	**100**	0	0	0	0
R1-2017	TLB (Mean buffer width = 25.3 m)	0.5 m	**10**	**10**	0	0	0
		3 m	**0**	0	0	0	0
		7.5 m	**40**	0	0	0	0
		20 m	**0**	0	0	0	0
	TRB (Mean buffer width = 60+ m)	0.5 m	**30**	**30**	0	0	0
		3 m	**10**	**10**	0	0	0
		7.5 m	0	0	0	0	0
		20 m	0	0	0	0	0
R2-2017	TLB (Mean buffer width = 18.2 m)	0.5 m	**70**	40	0	0	0
		3 m	**20**	0	0	0	0
		7.5 m	**20**	**20**	0	0	0
		20 m	**60**	0	0	0	0
	TRB (Mean buffer width = 27 m)	0.5 m	**40**	20	0	0	0
		3 m	0	0	0	0	0
		7.5 m	0	0	0	0	0
		20 m	0	0	0	0	0
R3-2017	TLB (Mean buffer width = 13.5 m)	0.5 m	0	0	0	0	0
		3 m	0	0	0	0	0
		7.5 m	**10**	**10**	0	0	0
		20 m	**80**	0	0	0	0
	TRB (Mean buffer width = 17.1 m)	0.5 m	**40**	**40**	0	0	0
		3 m	**20**	0	0	0	0
		7.5 m	**10**	**10**	0	0	0
		20 m	**60**	0	0	0	0

A comparison of key habitat parameters between the two control sites that were surveyed during the baseline and "Year One" surveys (C1 and C2) indicated significant site differences in mean substrate size (greater at site C1) and mean wetted width (greater at site C2) (Figure 3, Table 6). There was a significant site × year interaction for water depth (significantly greater at site C2 in 2016) and canopy cover (significantly less at site C1 in 2016) (Table 6). It is unclear why mean water depths were so different at site C2 between the two studies, while remaining similar at site C1. It is possible some downstream channel blockage was backing up water and increasing water depths during the Boffa Miskell (2016) survey (Figure 3). In contrast the difference in canopy cover was minor with the control sites continuing to have much greater cover than the three realignment sites (Figure 3).

Coefficients of variation for several habitat parameters that are commonly manipulated to increase instream habitat diversity indicated a 'mixed bag' when comparing control and realignment sites. Water depths were most variable at sites R1 and C2, with site R3 having the least variability (Table 7). Water velocity was most variable at sites R1 and R3 and least at C2 - although it should be noted mean velocities at all sites were very low (i.e., less than 0.1 m/s). While substrate size was greater at the three realignment sites, it was relatively uniform in size, meaning the C1 control site had much higher variability (Table 7). Wetted width was most variable at sites R1 and R2 and least at site R3 and C2. Coverage of leaf packs and woody debris and the counts of large boulders and wood jams were highest at the R1 and R2 realignment sites (Table 7). It was notable that no leaf pack, woody debris, or large boulders/wood jams were observed in the R3 realignment site (Table 7).

Table 6 **Results of the two-way analysis of variance (ANOVA) (with site and year as main factors) of the two control sites (C1 and C2). The Holm-Sidak *post-hoc* test was used to find which means were significantly different. n/s = not significant; n/a = not applicable. Water depth, substrate size, fine sediment, and canopy cover did not meet the normality assumption despite transformation.**

Habitat Parameter	Site	Year	Site × Year	Site Comparisons	Year or Interaction Comparisons
Water depth	$F_{1,20} = 16.32, p<0.001$	$F_{1,20} = 24.06, p<0.001$	$F_{1,20} = 21.78, p<0.001$	n/a	C2-2016>C2-2017=C1-2016=C2-2017
Water velocity	No test possible as baseline survey reported "negligible" velocities at both sites rather than values				
Substrate size	$F_{1,20} = 29.35, p<0.001$	n/s	n/s	C1>C2	n/a
Fine sediment cover	n/s	n/s	n/s	n/a	n/a
Wetted width	$F_{1,20} = 20.23, p<0.001$	n/s	n/s	C2>C1	n/a
Canopy cover	n/s	$F_{1,20} = 16.41, p<0.001$	$F_{1,20} = 16.01, p<0.001$	n/a	C1-2017=C2-2017=C2-2016>C1-2016

Table 7 The coefficient of variation (CV) of selected habitat parameters measured during the "Year One" survey at the two control sites (C1 and C2) and three realignment sites (R1, R2, R3). A data set of constant values (i.e., no variation) will have a CV of 0, while the higher the CV the more variable the data set. "None recorded" indicates where that feature was not observed at that site during the survey.

Habitat Parameter	C1	R1	R2	R3	C2
Water depth	0.22	0.69	0.30	0.18	0.67
Water velocity	0.62	0.76	0.61	0.84	0.15
Substrate size	0.73	0.12	0.09	0.08	$1.27E^{-16}$
Wetted width	0.29	0.57	0.65	0.19	0.19
Leaf packs	1.67	2.45	2.45	None recorded	None recorded
Woody debris	0.59	1.03	2.44	None recorded	0.94
Large boulders and wood jams	None recorded	0.63	2.44	None recorded	None recorded

3.2 Macroinvertebrates

3.2.1 Baseline Survey and Control Sites

The macroinvertebrate community of Kā Pūtahi was dominated by taxa that are common and widespread in low-gradient, predominantly soft-bottomed Canterbury streams (e.g., Ostracoda and Cladocera crustaceans, *Potamopyrgus* snails, Sphaeriidae pea clams, oligochaete worms, *Paracalliope* amphipod crustaceans, and non-biting *Chironomus* midge larvae) (Figure 4). Pollution sensitive EPT taxa were only represented by four caddisfly (Trichoptera) taxa (*Hudsonema amabile*, *Pycnocentria evecta, Oecitis unicolor*, and *Triplectides*) and a single lonely *Deleatidium* (Site C1 in "Year One" survey). These EPT taxa were found in very low numbers and combined accounted for only 0.18% and 1.08% of all macroinvertebrates captured in the baseline and "Year One" (control sites only) surveys respectively.

For the baseline survey, densities among the four sites were very similar, whereas the two remaining control sites of the "Year One" survey showed a large difference with site C1 having much greater densities than site C2 (Figure 5). Taxa richness varied somewhat between the baseline survey sites, but the two control sites did not vary much between surveys (Figure 5). The MCI and QMCI of all baseline survey sites and both control sites were all well within the "poor" interpretation category of Stark & Maxted (2007b). Site C1 had higher EPT taxa richness and percentage EPT values than the other baseline survey sites and C2 control site in the "Year One" survey (Figure 5).

A comparison of the two control sites (C1 and C2) between years (2016 (baseline survey); 2017 ("Year One" survey)) showed that for all community metrics with the exception of density, site C1 had significantly higher values that site C2 (Figure 5, Table 8). This indicates the habitat conditions of C1 are of higher quality than C2.

Figure 4 The five most abundant taxa at each site from the baseline survey (April 2016) and the "Year One" survey (January–February 2017). Baseline data was collected by Boffa Miskell (2016) and the "Year One" data by EOS Ecology. Note that only the C1 and C2 control sites were sampled during both surveys.

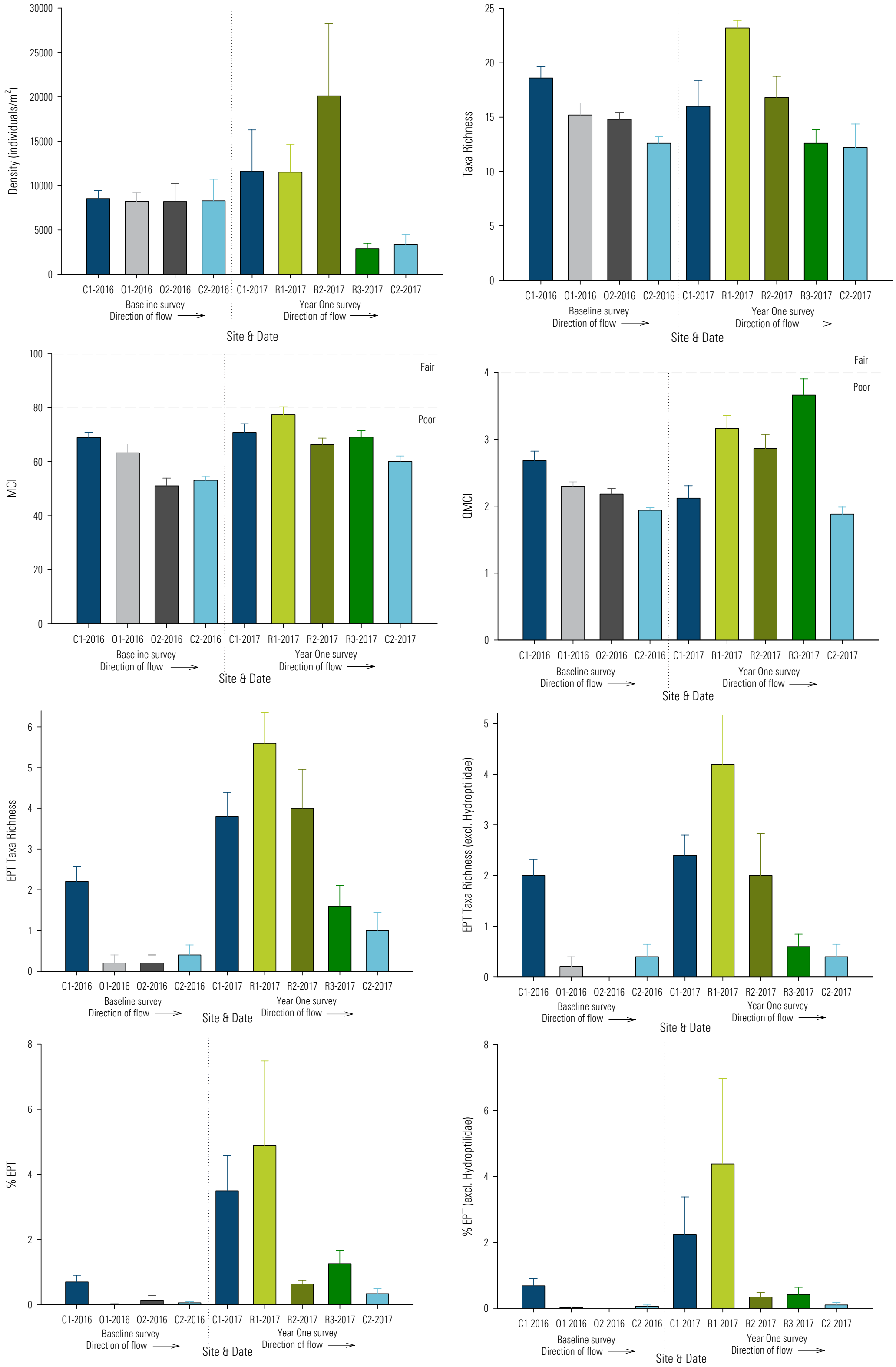


Figure 5 Mean invertebrate community metrics (+1 S.E.) from Kā Pūtahi sites from samples collected during the baseline and “Year One” surveys. Baseline data was collected by Boffa Miskell (2016) and the “Year One” data by EOS Ecology. Note that only the C1 and C2 control sites were sampled during both surveys.

Table 8 Results of the two-way analysis of variance (ANOVA) (with site and year as main factors) of the two control sites (C1 and C2). The Holm-Sidak *post-hoc* test was used to find which means were significantly different. n/s = not significant; n/a = not applicable.

Community Metrics	Site	Year	Site × Year	Site Comparisons	Year or Interaction Comparisons
Density	n/s	n/s	n/s	n/a	n/a
Taxa richness	$F_{1,19}$= 8.2, p=0.011	n/s	n/s	C1>C2	n/a
EPT taxa richness	$F_{1,19}$= 28.6, p<0.001	$F_{1,19}$= 6.5, p=0.021	n/s	C1>C2	2017>2016
% EPT abundance	$F_{1,19}$= 23,5, p<0.001	$F_{1,19}$= 11.4, p=0.004	n/s	C1>C2	2017>2016
EPT taxa richness (excl. hydropts)*	$F_{1,19}$= 34.1, p<0.001	n/s	n/s	C1>C2	n/a
% EPT abundance (excl. hydropts)*	$F_{1,19}$= 5.7, p=0.03	n/s	n/s	C1>C2	n/a
MCI	$F_{1,19}$= 34.1, p<0.001	n/s	n/s	C1>C2	n/a
QMCI	$F_{1,19}$= 14.2, p=0.002	$F_{1,19}$= 5.7, p=0.03	n/s	C1>C2	2016>2017

* Hydroptilidae trichopterans (*Oxyethira* spp. and *Paroxyethira* spp.) are excluded as they are algal piercers that are often abundant in nutrient-enriched waterways.

3.2.2 Control Sites vs. Realignment Sites

During the "Year One" survey three taxa were unique to the control sites while 12 taxa were unique to the realignment sites (Figure 6). These 12 taxa include four Diptera larvae (Empididae, Muscidae, *Paralimnophila*, *Zelandotipula*), of which only *Paralimnophila* was also found during the baseline survey. Most notable however, were the five Trichoptera taxa (*Hydrobiosis, Polyplectropus, Psilochorema, Pycnocentria, Pycnocentrodes*) unique to the realignment sites, with only *Pycnocentria* having been found during the baseline survey (Figure 6). All these taxa were uncommon with low relative abundances (Figure 6).

NMS ordination clearly indicated the realignment sites and control sites have distinct macroinvertebrate communities (Figure 4, Figure 7). Control sites (including oxbow sites) were completely separated from those of the realignment sites along NMS Axis 1 (Figure 7). ANOSIM results indicate there is a significant difference between the "control" and "realignment" groups (p=0.001) of moderate strength (R=0.7). SIMPER results show this difference is driven by higher abundance of *Potamopyrgus* snails, Sphaeriidae pea-clams, and Ostracoda and Cladocera crustaceans at the control sites and higher abundances of *Physa* snails, Orthocladiinae and *Chironomus* midge larvae, *Sigara* Hemiptera (water boatmen), oligochaete worms, and *Paracalliope* amphipods at the realignment sites (see Appendix 9.2 for full SIMPER results).

Analysis of macroinvertebrate community metrics indicated significant differences among all metrics except for density, although there were no clear distinctions between control and realignment sites (Table 9). However, of the five "Year One" survey sites, the R1 realignment site would appear to have best habitat conditions as it has the highest value for five, and second-highest value for another two, of the calculated community metrics (Figure 5, Table 9). Also notable was the relatively high QMCI score observed at realignment site R3, which resulted primarily from the very high abundance of *Sigara* (water boatmen) that have a relatively high MCI score (5) compared to most of the other dominant taxa encountered.

Figure 6 Macroinvertebrate taxa that were unique to control and realignment sites from the "Year One" sampling in January–February 2017. Relative abundances are shown in parentheses.

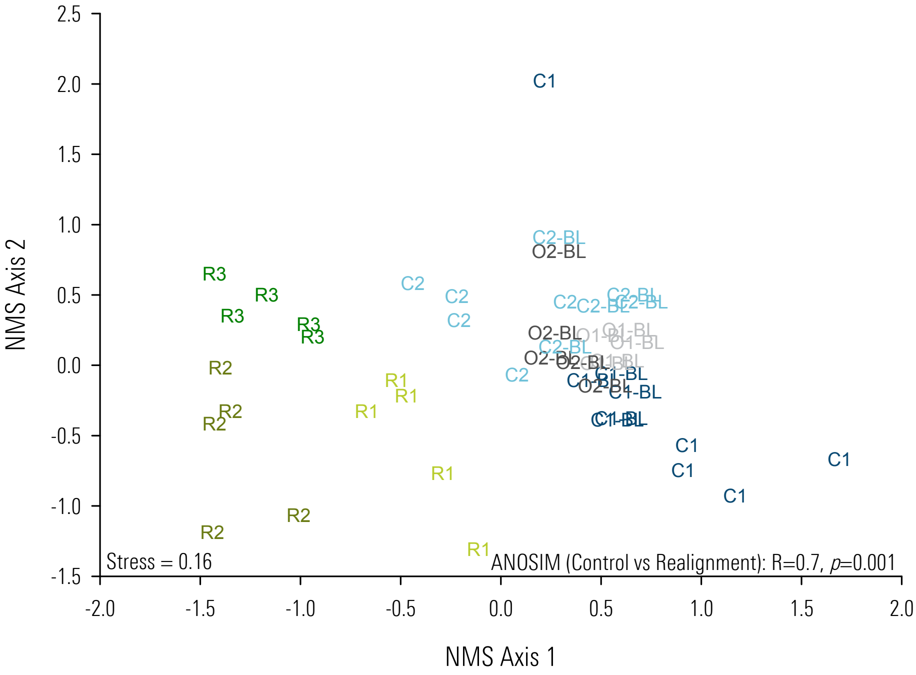


Figure 7 Non-metric multidimensional (NMS) ordination of macroinvertebrate community data from control sites (C1 and C2), oxbow sites (O1 and O2), and three realignment sites (R1, R2, R3) collected during the baseline survey by Boffa Miskell (denoted by "BL") and "Year One" survey by EOS Ecology. ANOSIM results with control and realignment as treatments are shown. A stress of 0.16 is indicative of an ordination that gives a potentially useful 2-dimensional picture (Clarke & Warwick, 2001).

Table 9 Results of the one-way analysis of variance (ANOVA) on community indices from the 2017 "Year One" survey. The Holm-Sidak *post-hoc* test (ANOVA) or Tukey test (Kruskal-Wallis) was used to find which site means (or medians) were significantly different. n/s = not significant; n/a = not applicable. Means (or medians) listed in descending order. For comparisons among means (or medians) the letters denote where there are differences (i.e., means or medians denoted with the same letter are not statistically different).

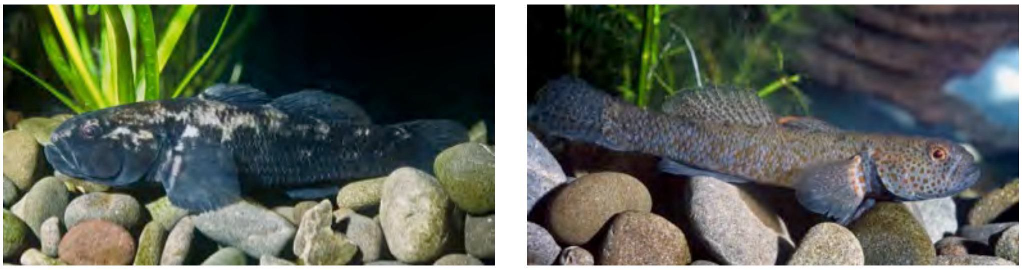
Community Metrics	ANOVA Result	Significant Site Differences
Density	n/s	n/a
Taxa richness	$F_{4,24}$= 6.1, p=0.002	R1: R2: C1: R3: C2 a ab ab b b
EPT taxa richness	$F_{4,24}$= 7.8, p<0.001	R1: R2: C1: R3: C2 ab ab abc bc c
% EPT abundance	$F_{4,24}$= 3.3, p=0.031	R1: C1: R3: R2: C2 too weak to detect
EPT taxa richness (excl. Hydroptilidae)*	$F_{4,24}$= 7.0, p=0.001	R1: C1: R2: R3: C2 a ab ab b b
% EPT abundance (excl. Hydroptilidae)*	H=12.93, p=0.012	C1: R1: R3: R2: C2 a ab ab ab b
MCI	$F_{4,24}$= 6.1, p=0.002	R1: C1: R3: R2: C2 a ab ab ab b
QMCI	$F_{4,24}$= 14.4, p<0.001	R3: R1: R2: C1: C2 a ab bc cd d

* Hydroptilidae trichopterans (*Oxyethira* and *Paroxyethira*) are excluded as they are algal piercers that are often abundant in nutrient-enriched waterways.

3.3 Fish

3.3.1 Overview

Six fish species were found in Kā Pūtahi over the course of the baseline and "Year One" surveys (Figure 8). The three bully species and shortfin eel are considered to not be threatened while inanga and longfin eel are "at risk – declining" (Goodman *et al.,* 2014). Longfin eels were only found during the baseline survey.



Common bully (Not Threatened)

Upland bully (Not Threatened)

Giant bully (Not Threatened)

Inanga (At Risk - Declining)

Shortfin eel (Not Threatened)

Longfin eel (At Risk - Declining)

Figure 8 Fish species captured in Kā Pūtahi during the baseline survey (Boffa Miskell, 2016) and "Year One" survey by EOS Ecology. The threat classification of Goodman *et al.* (2014) is given in parentheses. Photos © EOS Ecology.

3.3.2 Electrofishing (Year One Survey)

The "Year One" electrofishing survey of the fish community found the R1 and R2 realignment sites to have the highest fish species richness, with five and four species, respectively (Figure 9). Fish densities were greatest at the R2 and R3 realignment sites (Figure 9). There was a clear distinction in community composition with common bullies dominating the realignment sites and shortfin eels dominating at control sites (Figure 9). Upland bullies were also more prominent at the realignment sites. NMS ordination clearly separated the three realignment sites from the two control sites along NMS Axis 1, with an ANOSIM R-value of 1.0 indicative of complete separation of the realignment and control groups (although this was not significant due to the relatively large distances in ordination space between sites within each group)(Figure 10). SIMPER results indicate the control sites were separated from the realignments sites primarily due the higher densities of common bullies at the realignment sites and shortfin eels at the control sites (see Appendix 9.2 for full SIMPER results).

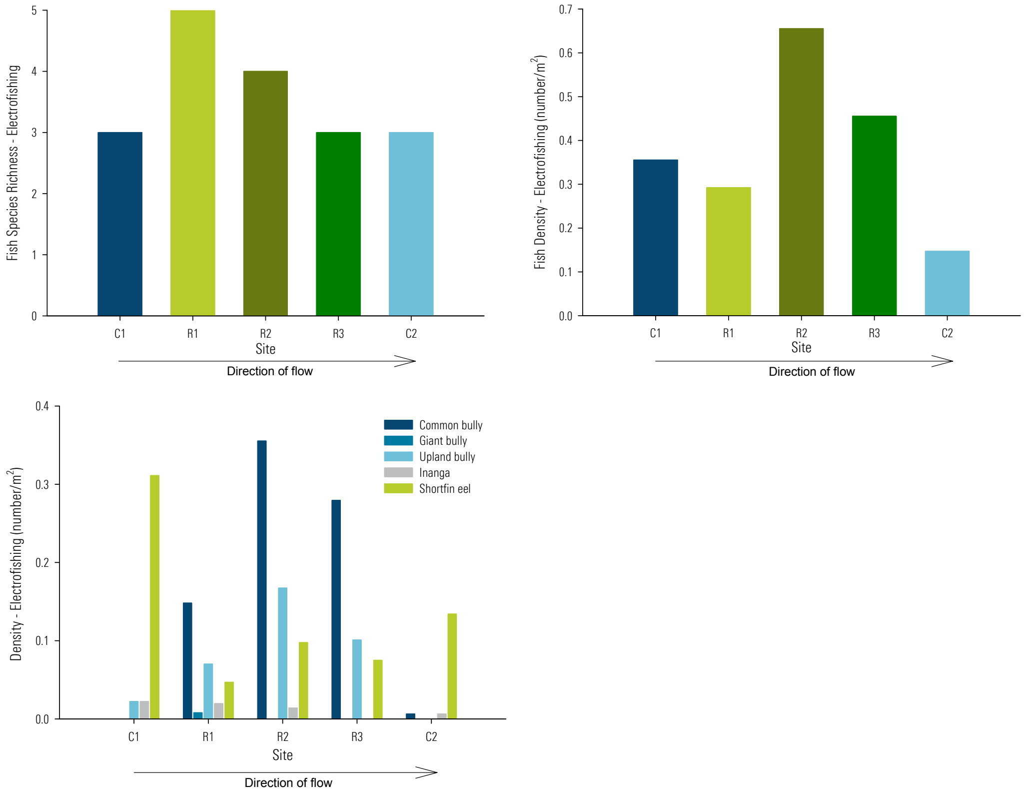


Figure 9 Fish species richness and densities from the “Year One” electrofishing survey at the two control sites (C1 and C2) and three realignment sites (R1, R2, R3).

Figure 10 Non-metric multidimensional (NMS) ordination of fish community data from two control sites (C1 and C2) and three realignment sites (R1, R2, R3) collected via electrofishing during the “Year One” survey by EOS Ecology. ANOSIM results with control and realignment as treatments are shown. A stress of 0.01 is indicative of an ordination that provides an excellent representation with no prospect of misinterpretation (Clarke & Warwick, 2001).

3.3.3 Trapping (All Years)

Based on fyke net and GMT data, fish species richness was greatest at the O1 oxbow site (now bypassed by the realignment section)(Figure 11). The two control sites had higher species richness during the baseline survey than the "Year One" survey. Considering just the "Year One" survey, the realignment sites had higher species richness than the two control sites, which matches the general relationship observed with the electrofishing data (Figure 10, Figure 11). GMTs caught very few fish during the baseline survey and no fish at the control sites during the "Year One" survey (Figure 11). In contrast at the realignment sites GMTs caught relatively high numbers of common bully (Figure 11). Fyke nets generally caught a higher number of fish species than GMT's and again common bullies were particularly abundant at the three realignment sites compared to all baseline survey and control sites (Figure 11). Overall the fish trapping data supports that collected via electrofishing, although it is notable that trapping data underrepresents the prominence of shortfin eel especially at the control sites during the "Year One" survey (Figure 10, Figure 11).

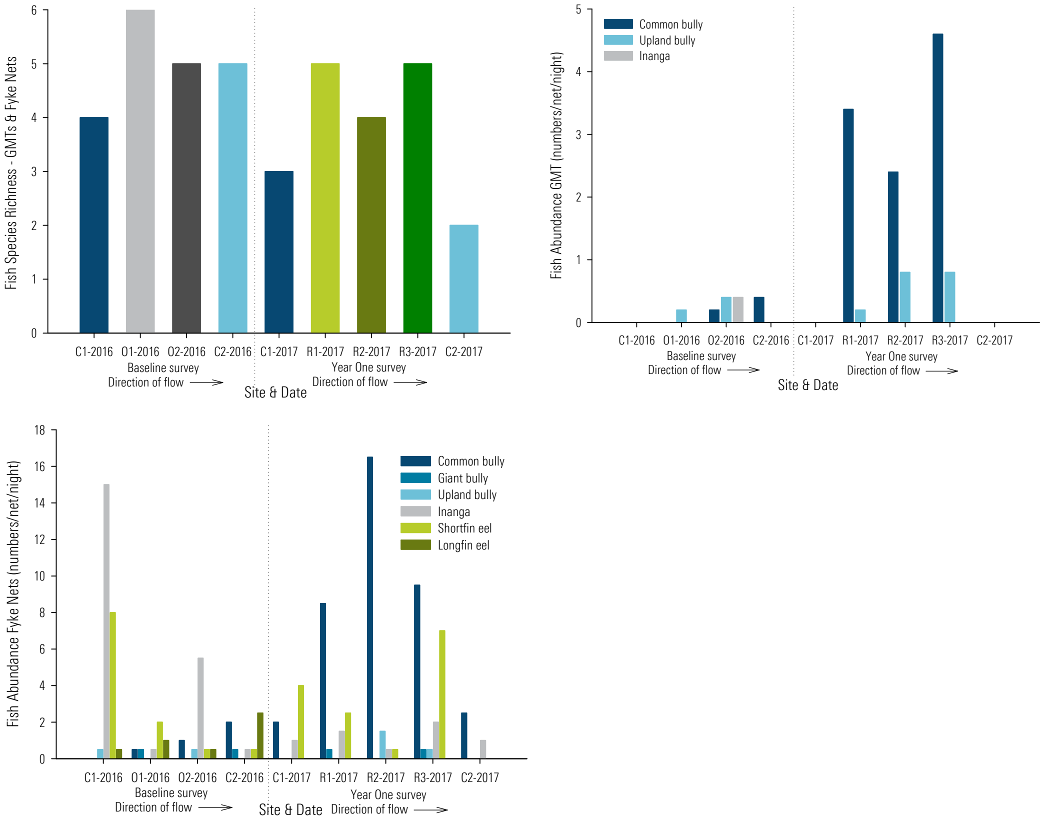


Figure 11 Fish species richness and densities from the Gee minnow trapping and fyke netting during the baseline survey (Boffa Miskell, 2016) and the "Year One" survey by EOS Ecology. Two fyke nets and five GMTs were set at each site for a single night.

4 DISCUSSION

4.1 Habitat

The realignment has created a section of stream with a stony bottom and open canopy, which strongly contrasts to the predominantly soft bottomed and shaded existing channel. Over time, as the riparian vegetation develops, the realignment channel will become more shaded; but it will be several years before any significant shading of the channel is achieved, and longer for those sections of channel that are several metres wide. Water velocities of the realignment were low and not much greater than those of the existing channel, due primarily to the wide channel profile creating very slow run or pool habitat. Narrower faster flowing riffle sections only accounted for a very small proportion of the habitats created in the realignment section. Given the generally fine sediment streambed of Kā Pūtahi upstream of the realignment, and the rural and urban land uses of the upstream catchment, it is highly likely that over time much of the stony bottom will gradually become covered in fine sediment. Our monitoring of fine sediment accumulation in response to instream habitat alterations undertaken as part of the Avon River Precinct anchor project (i.e., fine sediment removal, channel narrowing, gravel cleaning, gravel addition, gradient increases) indicated that channel narrowing combined with increasing channel gradient (and the subsequent resultant flow velocity increases) are required to maintain zones of relatively clean stony streambed (James & McMurtrie, 2015).

Given how recently the riparian area of the realignment has been planted, it was of no surprise the vegetation there was lower and sparser than the control sites. In general the riparian buffer width of the realignment sites are greater than those of the control sites and the former channel, which will provide sufficient area for a complex and self supporting vegetated riparian zone to develop over time.

While the realignment section did have some larger rocks/boulders and wood elements installed, these were sparse, such that the majority of the realignment section had limited habitat variability and cover for fish (especially in mid-channel areas). The result is that the control sites have greater fish cover than the realignment, particularly for larger eels. Recommendations for improving instream habitat values and variability were previously provided in McMurtrie (2017).

4.2 Macroinvertebrates

The aquatic macroinvertebrates of Kā Pūtahi are mostly taxa typical of slow-flowing, low gradient Canterbury waterways with catchments dominated by rural and urban land uses. There were however clear differences in the macroinvertebrate communities between control and realignment sites. The abundance of the snail *Potamopyrgus antipodarum* at the control sites and abundance of *Physa acuta* snails, Orthocladiinae midge larvae, and *Sigara* water boatmen at the realignment sites primarily drove this difference. The abundance of *P. acuta* snails in the realignment section is particularly notable as this is one of the few exotic aquatic macroinvertebrate species in Kā Pūtahi. *P. acuta* are common and widespread in New Zealand in a variety of freshwater habitats (Champion *et al.,* 2013).

Overall the differences in macroinvertebrate communities between the control and realignment sites result from shifts in the abundance of commonly encountered taxa rather than any new taxa appearing in the realignment in any great abundance. There were however several taxa that were present in the realignment sites but absent from the control sites during the "Year One" survey, including the caddisflies *Hydrobiosis, Polyplectropus, Psilochorema, Pycnocentria,* and *Pycnocentrodes*. These taxa were in very low abundances and are known from other Christchurch streams. Their appearance in the realignment section is likely related to their preference for stony-bottomed stream habitat and presence of suitable egg laying locations (e.g., exposed large rocks/boulders and woody debris).

All control and realignment sites have MCI and QMCI scores indicative of "poor" conditions according to the interpretation categories of Stark & Maxted (2007b). Given the pervasive negative effects on stream ecology of the rural and urban land use of the Kā Pūtahi catchment, it is unlikely the realignment section - despite its "improved" habitat - will achieve a large increase in MCI/QMCI scores. The overall effects of upstream catchment land use on water and habitat quality will always place constraints on the macroinvertebrate community, which cannot be overcome by instream and riparian habitat improvements in a relatively short section of a waterway. It is likely that a concomitant effort would be required elsewhere in the catchment, including addressing the significant sediment issues in the catchment, to achieve long-term lasting changes in the aquatic invertebrate community.control

4.3 Fish

The habitat differences between the control and realignment sites resulted in distinct fish assemblages driven primarily by the high abundance of common bullies at the realignment sites and higher abundance of shortfin eels at the control sites. The lack of significant fish cover for larger species in the realignment meant larger eels were rare, while smaller bodied bullies found conditions in the realignment particularly suitable. The small cobble stony substratum, abundance of macroinvertebrate prey, and perhaps a lack of larger eels have made the realignment a mecca for common bully in particular.

All the fish species found are known previously from Kā Pūtahi and other Christchurch waterways, hence the realignment has simply been colonised by the species already present, rather than any novel/new species appearing. As with the macroinvertebrate assemblage, overall effects of upstream catchment land use on water and habitat quality will always place constraints on the fish community that cannot be overcome by instream and riparian habitat improvements. That being said, provided there are no downstream barriers to fish migration and suitable habitat available, fish will usually tolerate degraded conditions to a greater extent than the more sensitive macroinvertebrate taxa.

While there may be some changes in the densities of some fish species over time as the realignment channel becomes more shaded and fine sediments accumulate, it is likely common bully will be the dominant species for many years to come.

4.4 Outcomes Assessment

No specific, measureable ecological goals (e.g., increase eel density, increase EPT taxa richness) were established for the Kā Pūtahi realignment, however Shadbolt (2015) outlined ten proposed outcomes that support the overall vision (see Introduction) for the realignment and naturalisation. Only a few of these could be measured within the scope of this "Year One" survey (Table 10). Of the outcomes with an aquatic ecology component only Outcome 1 (avoidance of fragmentation) can be said to be achieved although some of the constructed riffles apparently lost surface flow during low flow periods, which results in a level of periodic habitat fragmentation. It is too early to determine if there will be significant improvements to aquatic ecosystems (Outcome 3) or whether the silt traps will be effective (Outcome 4).

Table 10 **Assessment of proposed outcomes for the Kā Pūtahi realignment. Adapted from Table 3 of Shadbolt (2015).**

	Outcome	Assessment
1	Avoid unnecessary fragmentation of a natural waterway by exercising a precautionary approach.	Generally achieved although some constructed riffles may lack surface flow during low flows
2	Afford Kā Pūtahi an effective buffer between both the proposed motorway and proposed housing development that will overcome a range of edge effects such as high- temperatures, increased solar radiation, wind, noise, dust, and garden pest plant escapees that may otherwise impact adversely on the natural function and amenity of the natural waterway.	Out of scope to assess
3	Significantly improve both the aquatic and terrestrial ecosystems associated with Kā Pūtahi through good ecological design criteria based on appropriate reference waterways, riparian and terrestrial ecosystems.	Too early to assess, although lack of habitat variability may limit this in the future
4	Design and construct a series of features that will help trap silt in locations where it can easily be accessed and removed and thus prevent this material from being dispersed downstream.	Too early to assess, and assessing sediment retainment structures out of scope for this study
5	Provide flood capacity within the new waterway corridor through the creation of a series of wide floodplains.	Out of scope to assess but does appear achieved
6	Recognise and promote Tangata Whenua values associated with Kā Pūtahi and its environs through working in partnership with iwi and providing access to improved mahinga kai resources.	Out of scope to assess
7	Provide a high value, accessible recreational experience within the new stream corridor through the design and planting of landforms and other features that promote the dominance of natural character.	Out of scope to assess
8	Provide alternative walking routes through and around the proposed forested areas to satisfy Crime Prevention Through Environmental Deign (CPTED) criteria and principles.	Out of scope to assess
9	Ensure that Vision 2 of the Styx Vision 2000 – 2040 ("*to create a source to sea experience through the development of an Urban national Reserve*") is achievable in the long-term (Note: with the NZTA culvert options there are no provisions for public/pedestrians to access the ox-bow reach of Kā Pūtahi east of the motorway).	Out of scope to assess
10	Provide high quality landscape and amenity value for the proposed adjacent residential subdivision, including an effective sound and visual buffer between housing area and the proposed motorway.	Out of scope to assess

5 CONCLUSIONS

- The Kā Pūtahi realignment has essentially created a section of hard-bottomed, low velocity habitat with a broad riparian buffer in a stream dominated by soft-bottomed, low velocity conditions. The wider sections of the realignment section will also have minimal overhead shade for several years until the riparian plantings attain a height sufficient to provide significant shade.
- The realignment section with its open canopy and stony stream bottom has macroinvertebrate and fish assemblages distinct to those of the original Kā Pūtahi channel.
- The realignment section appeared to be particularly suitable for the exotic aquatic snail, *Physa acuta* that was in high densities compared to the original Kā Pūtahi channel where the endemic snail *Potamopyrgus antipodarum* dominated.
- The realignment section did have very low densities of five caddisfly taxa that were absent from the original channel during the "Year One" survey, which is encouraging.
- The realignment section had high densities of common bully and currently does not provide suitable habitat for large bodied fish, in particular eels.
- Given this survey was undertaken within a year of construction, the realignment section was in an early stage of succession, hence it would be premature to make any definitive statements regarding whether the instream works have increased ecological values within Kā Pūtahi. At best we have documented an early successional stage of the realignment and long term monitoring will be required to truly determine if ecological values have indeed been increased.

6 RECOMMENDATIONS

- Modify the riffle sections that have lacked surface flow during low flow conditions such that the realignment section has continuous surface water connectivity all year round. This may require lining of the riffle with impervious or semi-impervious material.
- The physical habitat of the realignment section could be greatly improved to provide more habitat variability, namely increased fish cover and more riffle habitat with faster water velocities. Potential improvements are outlined in McMurtrie (2017). At the time of writing, council ecologists and engineers were evaluating options for further enhancing physical habitat along the realignment, with the intention of carrying out physical works in 2017 (Dr Greg Burrell, CCC, pers. comm.).
- It is not too late to develop some realistic and measureable ecological goals for the project to help guide further monitoring (e.g., increased abundance of eels compared to control sites, increased EPT taxa richness and/or densities compared to control sites, etc.).
- Undertake further monitoring in five years time to allow sufficient time for successional processes to occur and the riparian plantings to establish. If higher resolution information on succession is desired then consider collecting the field data at shorter intervals, but delaying analysis and reporting until at least five years has elapsed.
- Consider more targeted monitoring rather than just general macroinvertebrate and fish sampling:
    - Adult insect trapping to determine which species are present to potentially colonise any improved habitat in the realignment.
    - Caddisfly egg mass monitoring to determine if the installation of large stable habitat features (boulders, wood) have lead to an increase in oviposition by species that use

  such habitat for this purpose.

  - Monitoring of sediment build-up in sediment traps to facilitate removal when required.

7 ACKNOWLEDGEMENTS

Thanks to all the EOS Ecology staff involved in all stages of this project.

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9 APPENDICES

9.1 Site Photographs

Site C1 Kā Pūtahi control site (looking downstream from top of site)

Site C1 Kā Pūtahi control site (looking upstream from bottom of site)

Site C2 Kā Pūtahi control site (looking downstream from top of site)

Site C2 Kā Pūtahi control site (looking upstream from bottom of site)

Site R1 Kā Pūtahi realignment site (looking downstream from top of site)

Site R1 Kā Pūtahi realignment site (looking upstream from bottom of site)

Site R2 Kā Pūtahi realignment site (looking downstream from top of site)

Site R2 Kā Pūtahi realignment site (looking upstream from bottom of site)

Site R3 Kā Pūtahi realignment site (looking downstream from top of site)

Site R3 Kā Pūtahi realignment site (looking upstream from bottom of site)

9.2 SIMPER Results

Table A1 SIMPER results for baseline and "Year One" macroinvertebrate data. The survey sites were grouped into "Control" (C1, C2, O1, O2) and "Realignment" (R1, R2, R3) for analysis. Average dissimilarity = 88.84.

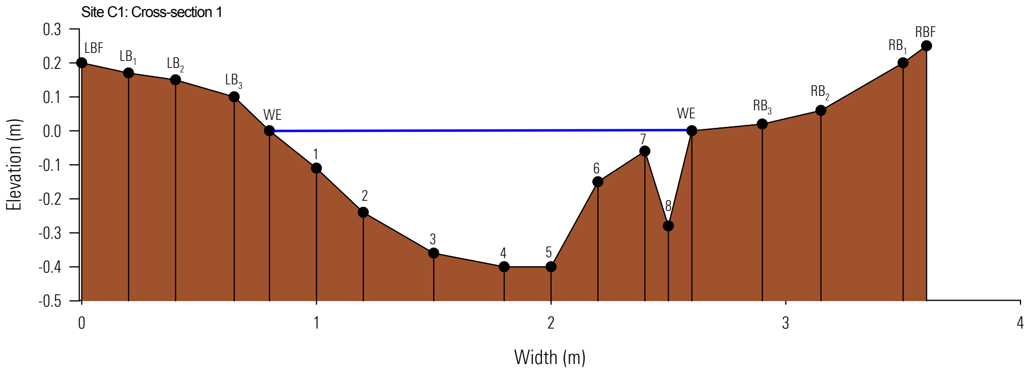
Species	Group Control Av. Abund	Group Realignment Av. Abund	Av. Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus antipodarum	282.7	0.07	15.59	0.79	17.55	17.55
Physa acuta	21.13	360.6	15.11	1.05	17.01	34.56
Ostracoda	218.6	73.93	15.02	1.2	16.91	51.47
Orthocladiinae	1.4	274.8	9.98	0.95	11.23	62.7
Sigara	0.83	88.07	7.5	1.05	8.44	71.14
Oligochaeta	57.47	103.8	5.84	0.84	6.57	77.71
Paracalliope fluviatilis	22.23	52.73	3.64	0.55	4.09	81.8
Chironomus	15.13	46	2.95	0.73	3.32	85.12
Sphaeriidae	35.23	0	2.52	0.93	2.83	87.95
Cladocera	36.07	2.47	2.39	0.74	2.69	90.64

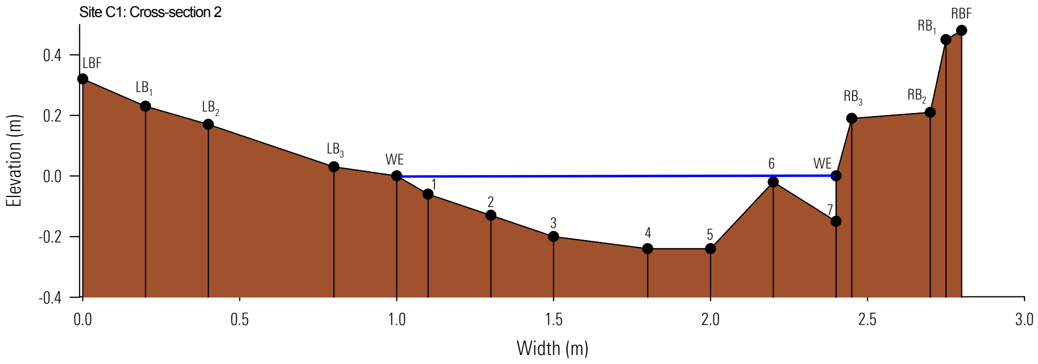
Table A2 SIMPER results for "Year One" electrofishing survey data. The five survey sites were grouped into "Control" (C1, C2) and "Realignment" (R1, R2, R3) for analysis. Average dissimilarity = 76.11.

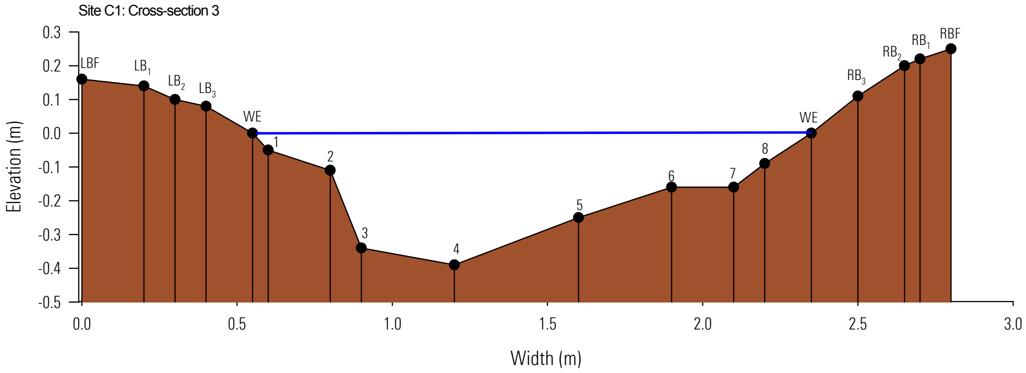
Species	Group Control Av. Abund	Group Realignment Av. Abund	Av. Diss	Diss/SD	Contrib%	Cum.%
Common bully	0	0.26	36.07	4.37	49.35	49.35
Shortfin eel	0.22	0.07	21.13	1.6	28.91	78.26
Upland bully	0.01	0.11	14.38	2.84	19.67	97.93

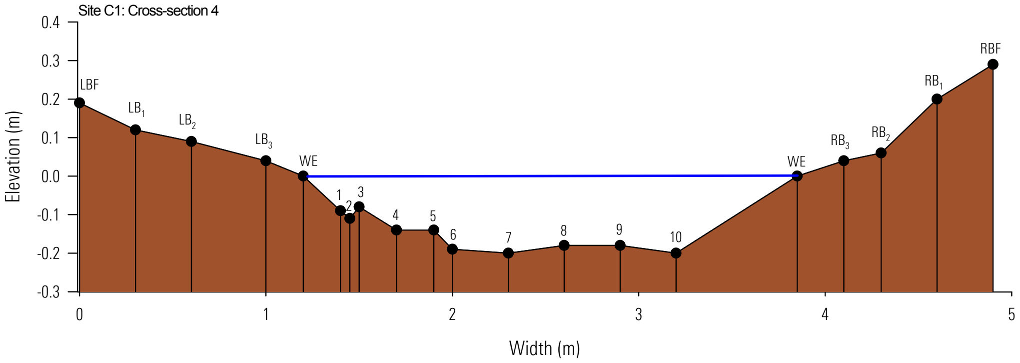
9.3 Channel Profile Cross-sections

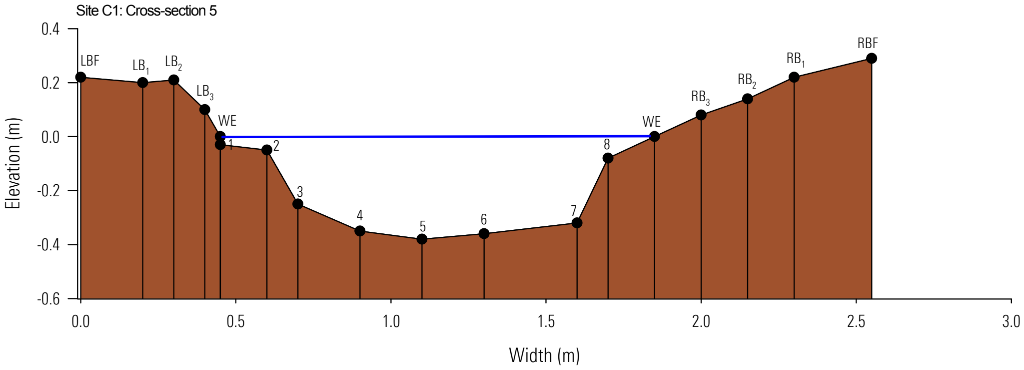
Key: LBF = left bankfull height; LB_1–LB_3 = up to three points between LBF & WE; WE = waters edge; 1–10 – up to ten water depth offsets; RB_1–RB_3 = up to three points between RBF & WE; RBF = right bankfull height; blue line indicates water surface at time of measurements. For elevation, negative points indicate water depths and positive values indicate bank measurements.

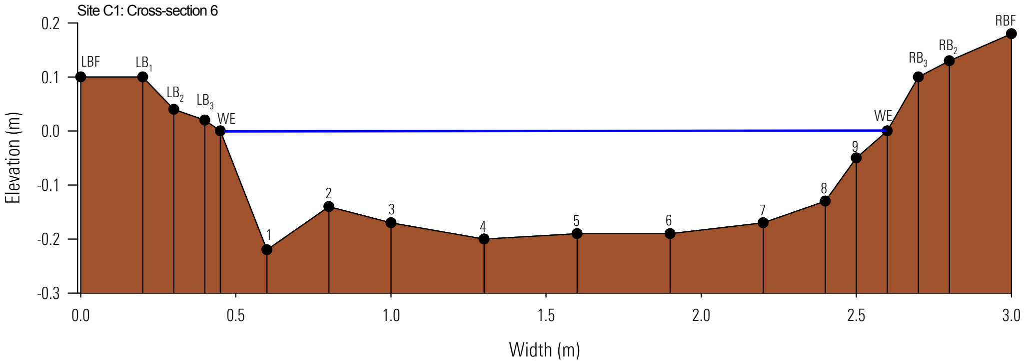







Site C1: Cross-section 4
Elevation (m)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
Width (m)
0
1
2
3
4
5
LBF
LB_1
LB_2
LB_3
WE
1
2
3
4
5
6
7
8
9
10
WE
RB_3
RB_2
RB_1
RBF


Site C1: Cross-section 5
Elevation (m)
0.4
0.2
0.0
-0.2
-0.4
-0.6
Width (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
LBF
LB_1
LB_2
LB_3
WE
1
2
3
4
5
6
7
8
WE
RB_3
RB_2
RB_1
RBF


Site C1: Cross-section 6
Elevation (m)
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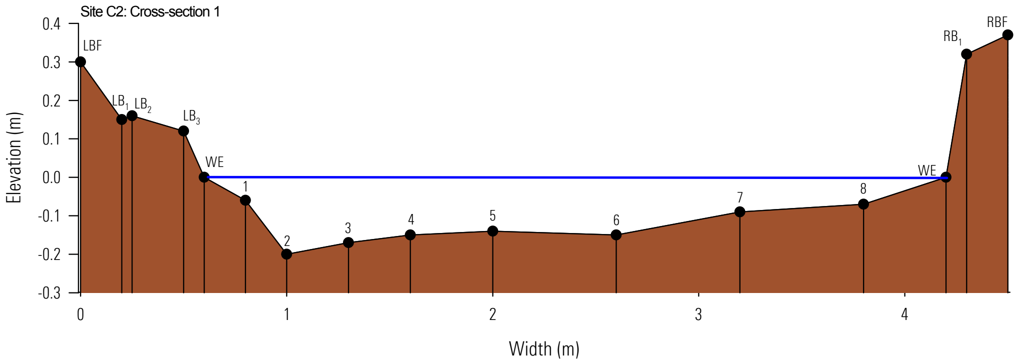
0.1
0.0
-0.1
-0.2
-0.3
Width (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
LBF
LB_1
LB_2
LB_3
WE
1
2
3
4
5
6
7
8
9
WE
RB_3
RB_2
RBF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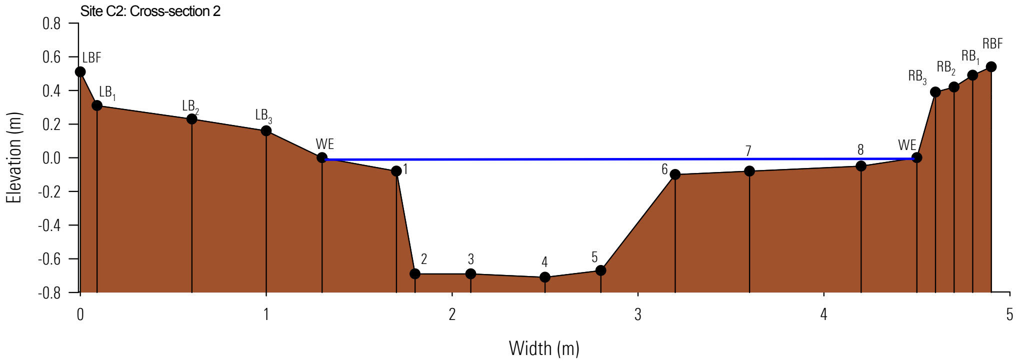
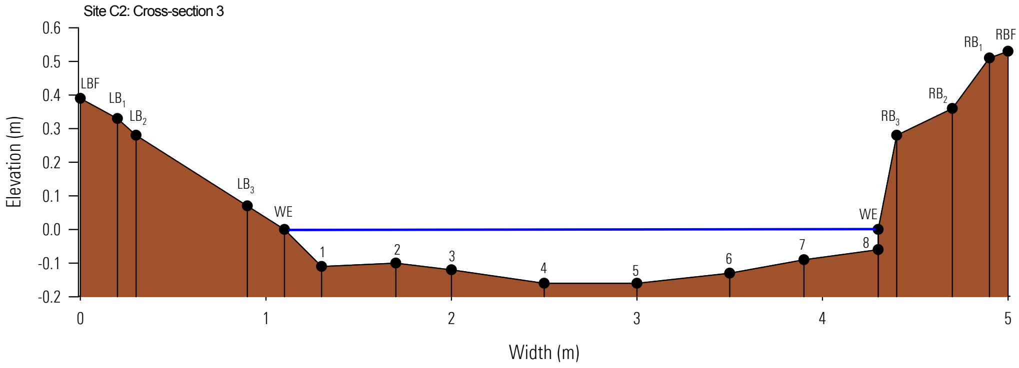
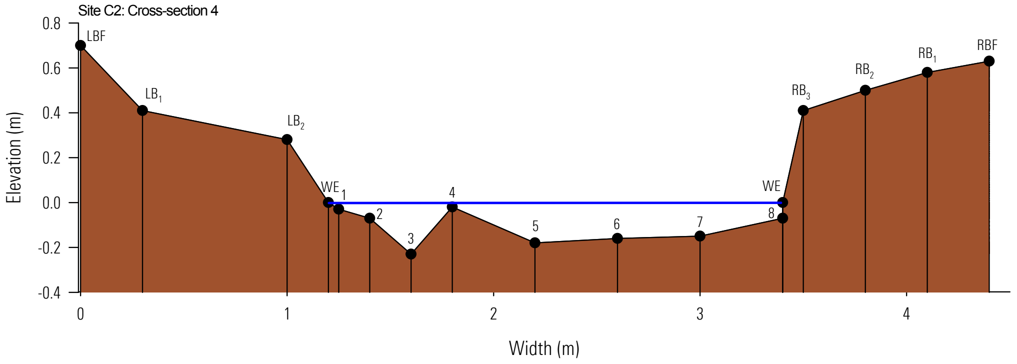
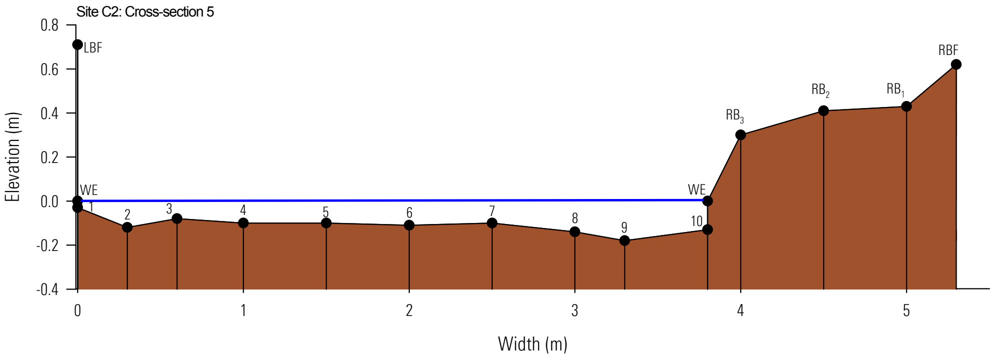
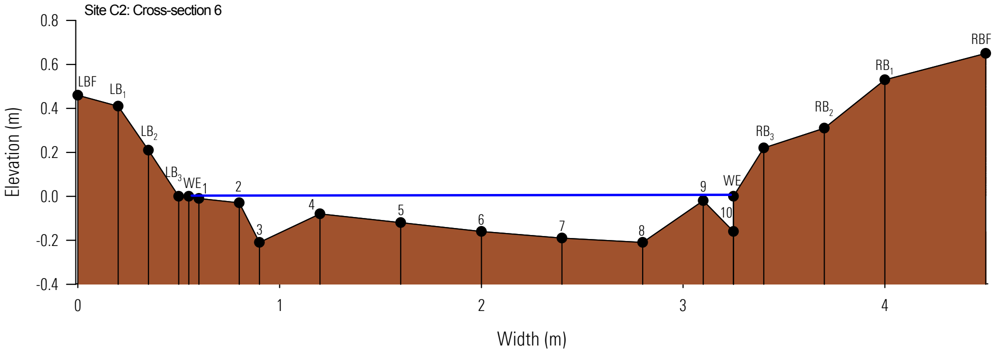
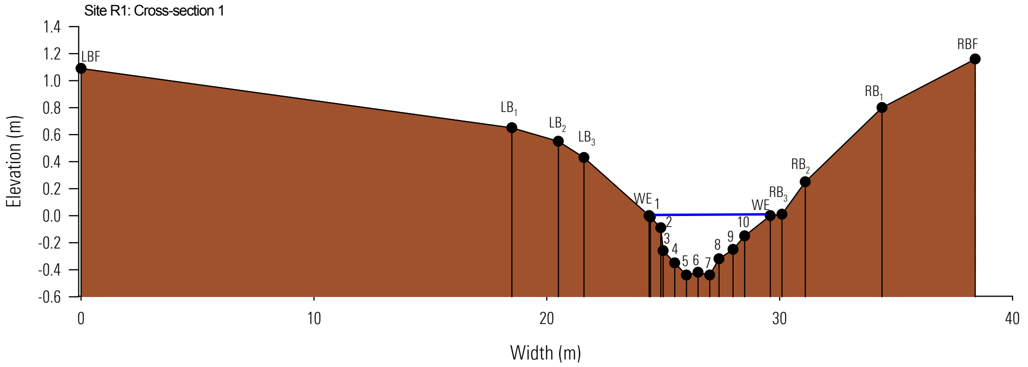

Site C2: Cross-section 2

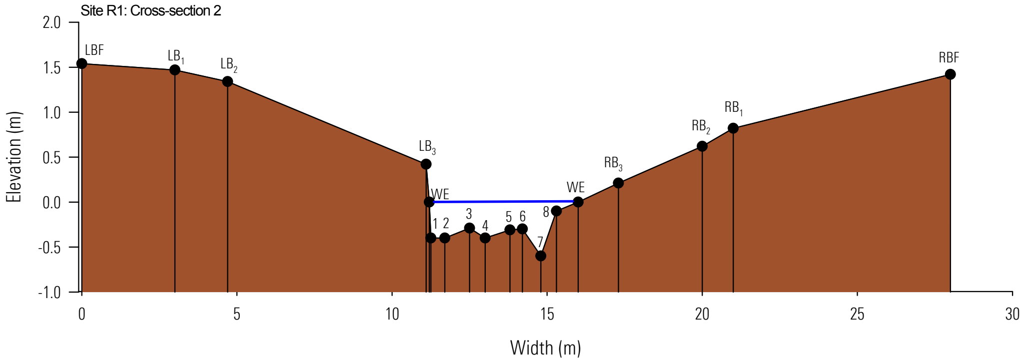

Site C2: Cross-section 3

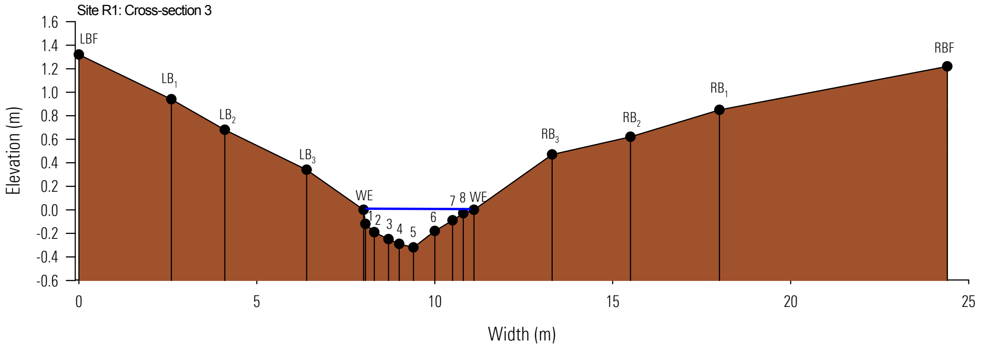

Site C2: Cross-section 4

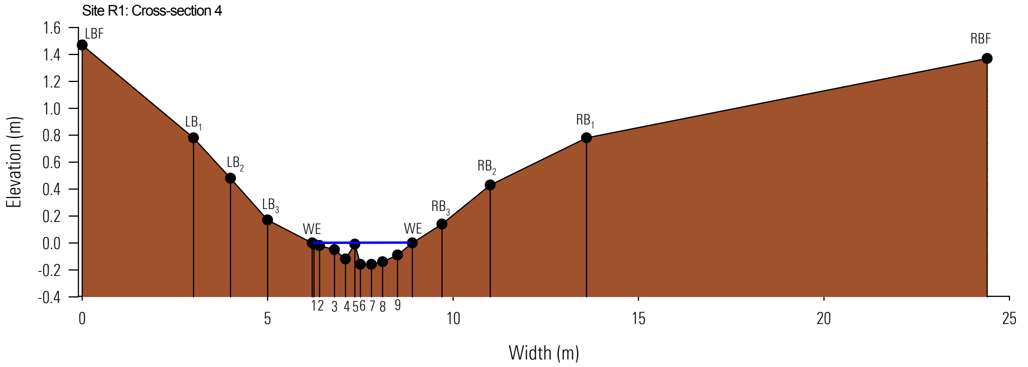

Site C2: Cross-section 5
Elevation (m)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
LBF
WE
1
2
3
4
5
6
7
8
9
10
WE
RB$_3$
RB$_2$
RB$_1$
RBF
0
1
2
3
4
5
Width (m)

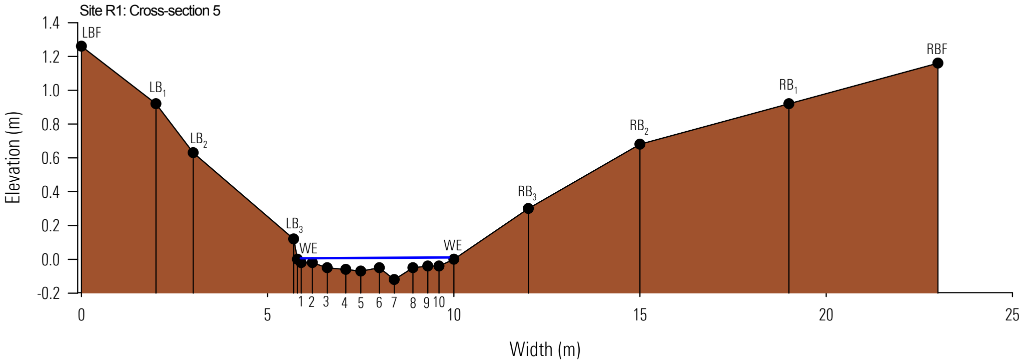

Site C2: Cross-section 6
Elevation (m)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
LBF
LB$_1$
LB$_2$
LB$_3$
WE
1
2
3
4
5
6
7
8
9
WE
10
RB$_3$
RB$_2$
RB$_1$
RBF
0
1
2
3
4
Width (m)


Site R1: Cross-section 1
Elevation (m)
Width (m)
LBF
LB1
LB2
LB3
WE
1 2 3 4 5 6 7 8 9 10
WE
RB3
RB2
RB1
RBF
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
10
20
30
40

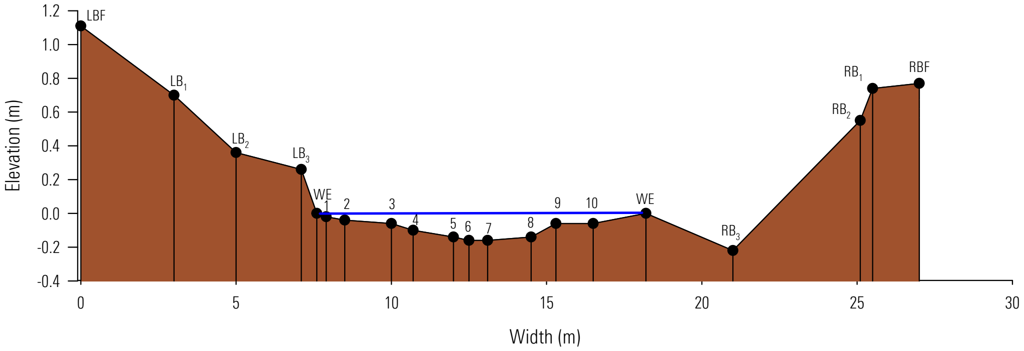

Site R1: Cross-section 2
Elevation (m)
Width (m)
LBF
LB1
LB2
LB3
WE
1 2 3 4 5 6 7 8
WE
RB3
RB2
RB1
RBF
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
5
10
15
20
25
30


Site R1: Cross-section 3
Elevation (m)
Width (m)
LBF
LB1
LB2
LB3
WE
1 2 3 4 5 6 7 8
WE
RB3
RB2
RB1
RBF
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
5
10
15
20
25

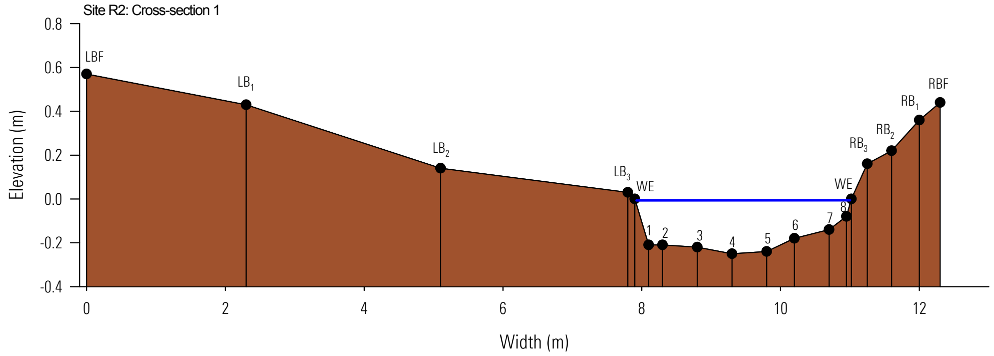

Site R1: Cross-section 4
Elevation (m)
Width (m)
LBF
LB1
LB2
LB3
WE
1 2 3 4 5 6 7 8 9
WE
RB3
RB2
RB1
RBF
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
5
10
15
20
25



Site R1: Cross-section 5



Site R1: Cross-section 6


Site R2: Cross-section 1
Elevation (m)
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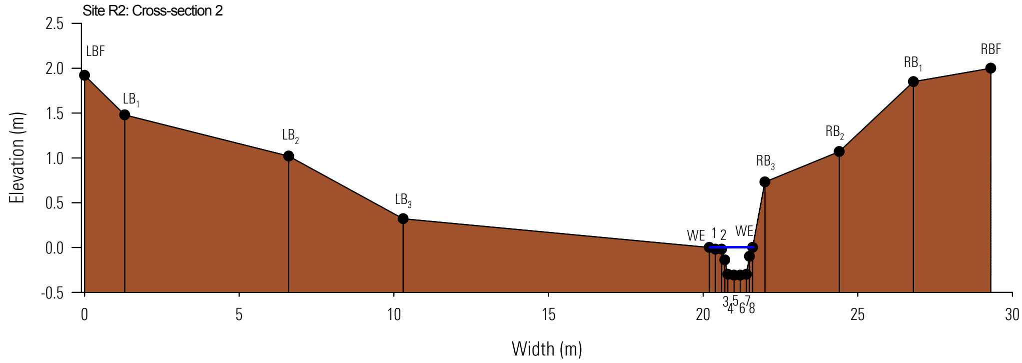
0.6
0.4
0.2
0.0
-0.2
-0.4
Width (m)
0
2
4
6
8
10
12
LBF
LB1
LB2
LB3
WE
1
2
3
4
5
6
7
8
WE
RB3
RB2
RB1
RBF


Site R2: Cross-section 2
Elevation (m)
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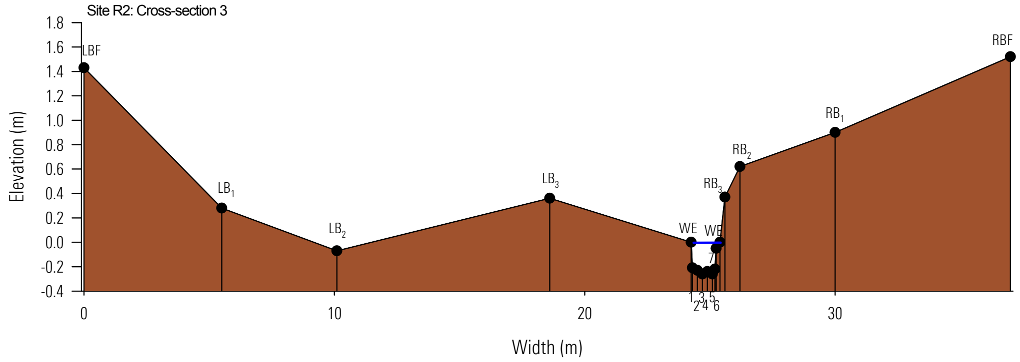
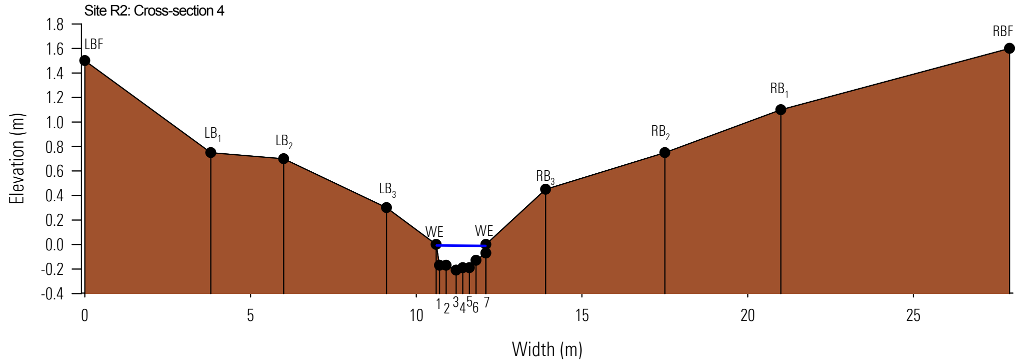
2.0
1.5
1.0
0.5
0.0
-0.5
Width (m)
0
5
10
15
20
25
30
LBF
LB1
LB2
LB3
WE
1 2
WE
3 5 7
4 6 8
RB3
RB2
RB1
RBF


Site R2: Cross-section 3
Elevation (m)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
Width (m)
0
10
20
30
LBF
LB1
LB2
LB3
WE
WE
7
1 3 5
2 4 6
RB3
RB2
RB1
RBF


Site R2: Cross-section 4
Elevation (m)
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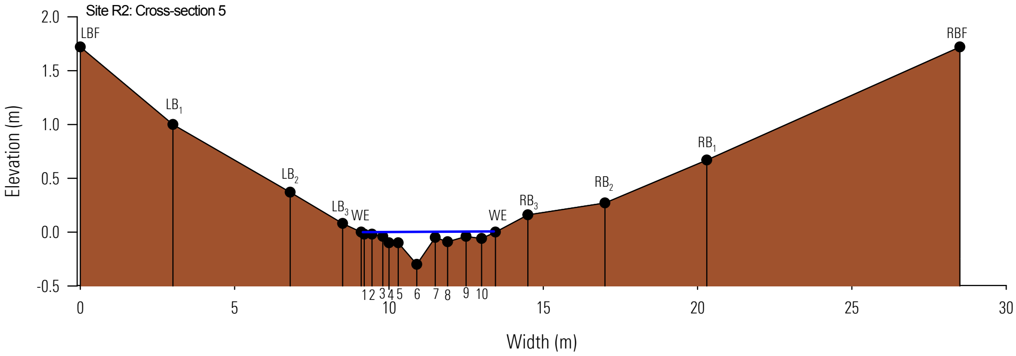
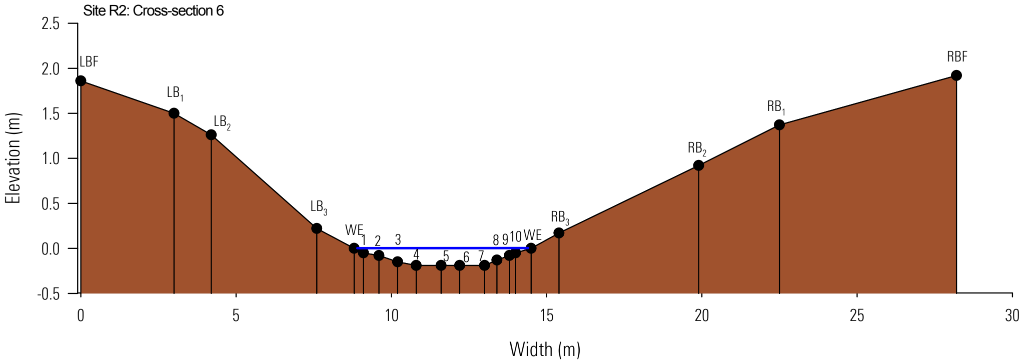
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
Width (m)
0
5
10
15
20
25
LBF
LB1
LB2
LB3
WE
WE
1 2 3 4 5 6 7
RB3
RB2
RB1
RBF


Site R2: Cross-section 5
Elevation (m)
2.0
1.5
1.0
0.5
0.0
-0.5
LBF
LB_1
LB_2
LB_3
WE
1 2 3 4 5 6 7 8 9 10
WE
RB_3
RB_2
RB_1
RBF
0
5
10
15
20
25
30
Width (m)


Site R2: Cross-section 6
Elevation (m)
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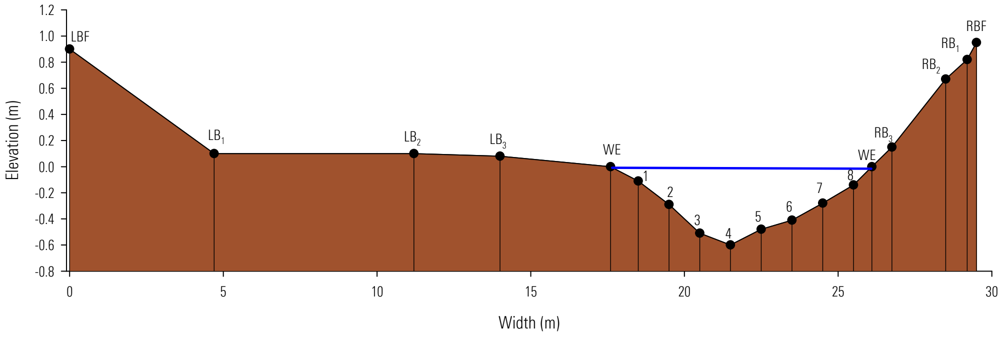
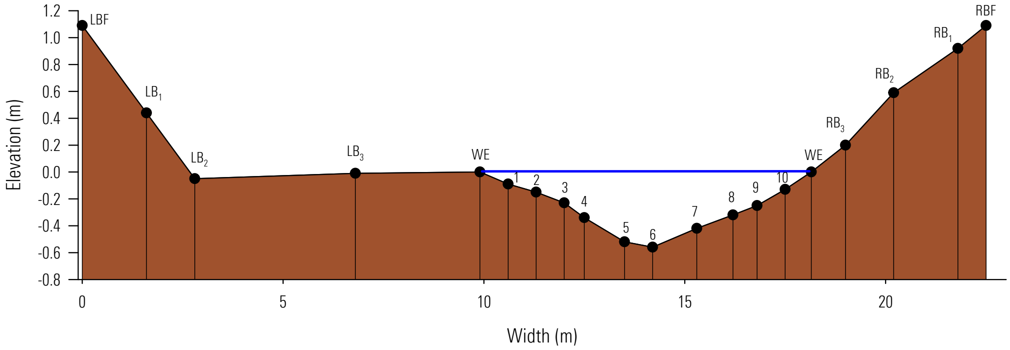
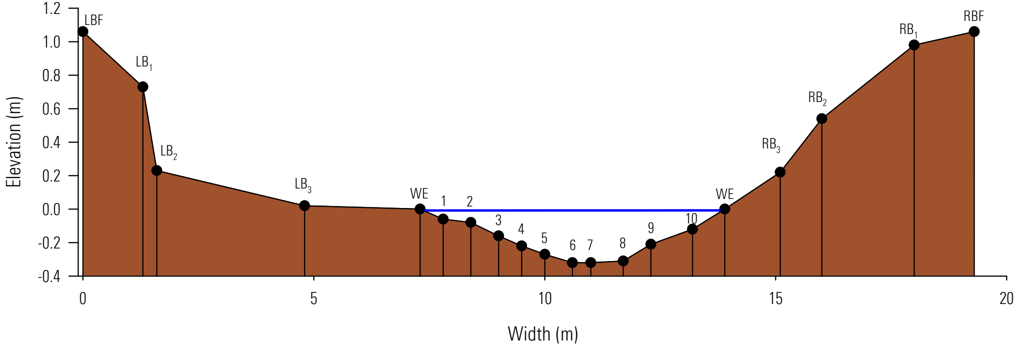
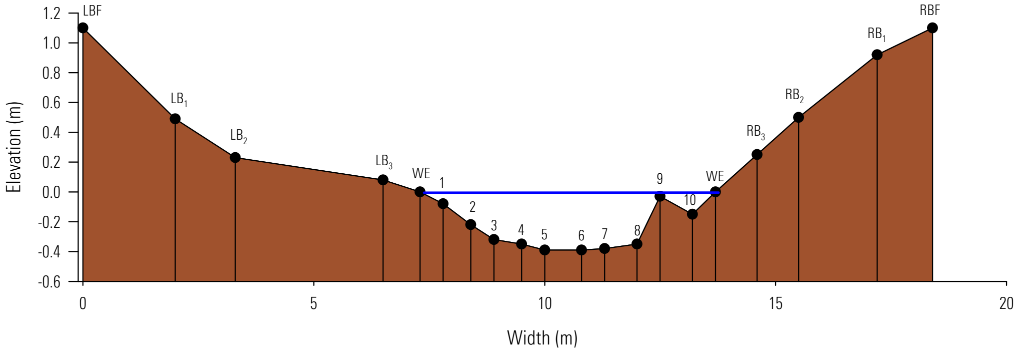
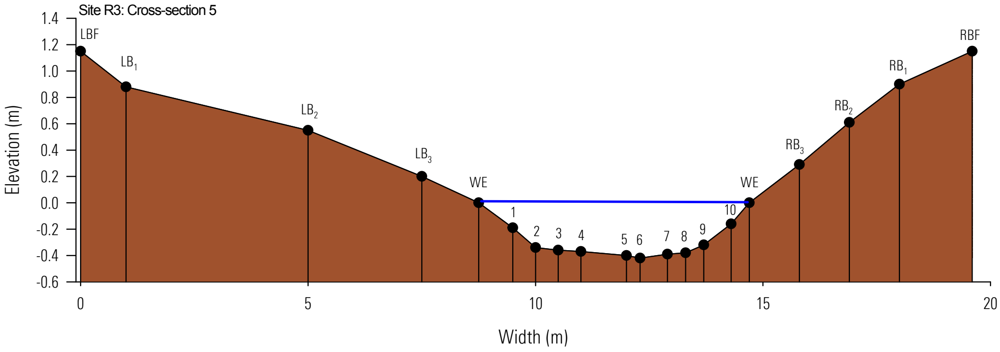
2.0
1.5
1.0
0.5
0.0
-0.5
LBF
LB_1
LB_2
LB_3
WE
1 2 3 4 5 6 7 8 9 10
WE
RB_3
RB_2
RB_1
RBF
0
5
10
15
20
25
30
Width (m)

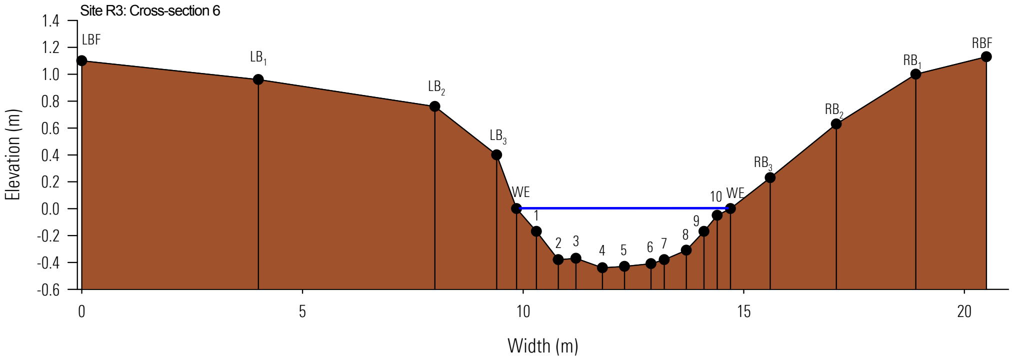

Site R3: Cross-section 1


Site R3: Cross-section 2


Site R3: Cross-section 3


Site R3: Cross-section 4


Site R3: Cross-section 5
Elevation (m)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
LBF
LB_1
LB_2
LB_3
WE
1
2
3
4
5
6
7
8
9
10
WE
RB_3
RB_2
RB_1
RBF
0
5
10
15
20
Width (m)


Site R3: Cross-section 6
Elevation (m)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
LBF
LB_1
LB_2
LB_3
WE
1
2
3
4
5
6
7
8
9
10
WE
RB_3
RB_2
RB_1
RBF
0
5
10
15
20
Width (m)

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