Cashmere Stream Baseline Aquatic Ecology Survey

July 2016

Prepared for:
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EXECUTIVE SUMMARY

The upper reaches of Cashmere Stream flow through farmland to the southwest of Christchurch that is zoned for residential development. The purpose of this report is to describe the current ecological state of Cashmere Stream in the area of proposed development and to provide recommendations for stream restoration.

Fieldwork in late April and early May 2016 found that stream pH, conductivity, and water temperatures were all typical for Christchurch spring-fed streams. Stream water dissolved oxygen saturation was low due to the large flow contribution from springs in Bunz Drain that have naturally low dissolved oxygen concentrations.

Cashmere Stream in the study area is artificially straight and deeply incised, with steep banks, minimal shading and negligible instream flow diversity. There is minimal native vegetation in the riparian zone, which is dominated by pasture grass and weeds. The substrate is dominated by fine sediments (<2 mm diameter) at all sites. Macrophytes provide some cover and habitat for invertebrates and fish, but habitat quality is degraded when macrophyte cover is too high, due to impacts on flow and oxygen concentrations.

The invertebrate community was dominated by pollution-tolerant snails and crustaceans, reflecting the poor quality aquatic habitat present. However, koura (freshwater crayfish) were found at one site and it is likely they occur throughout the upper reaches of Cashmere Stream. Koura are of interest due to their declining conservation status and their value as mahinga kai. Kākahi (freshwater mussels) have not been recorded from the study area, but empty shells have been previously been found a short distance upstream. Kākahi also have a declining status. The freshwater fish community was dominated by shortfin eels and upland bullies, which are common and widespread species. Shortfin eel are also valued mahinga kai. Longfin eel and inanga (whitebait) are also likely present and they are of ecological interest due to their declining conservation status and their value as mahinga kai.

We suggest that the restored stream should be designed to provide a mix of deeper, low gradient pool habitats for larger fish such as eels and trout, and steeper gravel/cobble habitat for juvenile eels and bullies. The broad restoration goal should be increased diversity and abundance of native plants and fish. Aquatic biodiversity should be increased through the provision of increased habitat diversity, protecting (and possibly enhancing) water quality, and reducing disturbance from regular macrophyte and sediment removal.

We recommend the following restoration actions (see report body for details):

- Use of best practice stormwater treatment, including removal of fine loess sediment prior to discharging to surface water.
- Replace the existing straight channel with a new meandering channel containing a mix of run, riffle, and pool habitat, to increase habitat diversity. Batter the banks back to reduce bank angles and avoid bank undercutting and erosion.
- Create a narrow, v-shaped low flow channel at the base of Quarry Road Drain and Cashmere Stream upstream of Bunz Drain, to provide adequate aquatic habitat during low flows.
- Place pools upstream of riffles to help settle-out fine sediments, and also consider placing pools in locations accessible to diggers to enable future sediment removal.

- Place logs, root-wads and boulders in the channel to provide aquatic habitat.
- Avoid piping Quarry Road Drain.
- Plant native vegetation up to the water's edge, to provide a buffer to the stream, shade-out nuisance macrophytes and periphyton, and provide habitat for invertebrates and fish.
- Protect Bunz Drain springs, because of their impressive size, their biodiversity and cultural value, and because they are a major flow source to Cashmere Stream.
- Place a riffle in Cashmere Stream downstream of Bunz Drain to help reaerate the deoxygenated spring water.
- If Sutherland Road culvert is upgraded, consider excluding brown trout, while maintaining or enhancing upstream passage for native inanga and common bully.
- Salvage fish, koura and kākahi prior to diverting flow to the new channel alignment.
- Undertake follow-up ecological monitoring to determine restoration success once the new channel has been completed. Monitoring should continue over a number of years, to allow adequate time for biological communities to establish in the new habitat.

1. INTRODUCTION

Cashmere Stream is a major tributary of the Heathcote River that arises to the southwest of Christchurch. The upper reaches of Cashmere Stream flow through farmland that is zoned for residential development. Christchurch City Council (CCC) is designing a stormwater treatment facility and aims to restore Cashmere Stream habitat on land it owns between Sutherland Road and the confluence with Hoon Hay Valley Stream (Figure 1). This restoration activity in upper Cashmere Stream will complement recent restoration work completed upstream of Sutherlands Road and future work proposed further downstream.

This report describes the results of an aquatic ecology survey of Cashmere Stream, undertaken as a pre-restoration baseline. The purpose of this report is to describe the current state of aquatic habitat, water quality and ecology, and provide recommendations for restoration.

Fieldwork was undertaken in late April and early May 2016, approximately two weeks after mechanical weed removal had occurred in Cashmere Stream. Weed removal likely reduced the abundance and diversity of fish communities, but fieldwork could not be delayed to the following summer, due to impacts on construction timeframes. Potential implications of fieldwork timing are discussed in the results section.

2. METHODS

2.1. Study Area

Cashmere Stream was once part of an extensive swamp that was drained by European settlers. The upper reaches of Cashmere Stream sampled for this report are now located in farmland grazed by cattle and horses. While the lower reaches of Cashmere Stream retain a natural, meandering path, the upper reaches are uniformly straight, which reflects the drainage function they were originally dug for.

Cashmere Stream is predominantly spring-fed during baseflow conditions. Several large springs in the lower reaches of Bunz Drain contribute most of the flow to Cashmere Stream downstream of its confluence. Following rainfall, stormwater from adjacent farmland and downstream residential landuse can rapidly increase flows and turbidity. Site 5 is downstream of tributaries draining residential landuse in Westmorland and new developments in the Miln Drain catchment. Suspended and deposited fine sediment are key environmental issues in the catchment, with the sediment sourced from eroding hills, stream banks, and runoff from residential and rural land use (McMurtrie & James 2013).

Six sampling sites were chosen by CCC, including four sites between Sutherlands Road and Hoon Hay Valley Stream (i.e., where restoration work is proposed), and two sites downstream (Figure 1; Table 1). Site 1 on Cashmere Stream was the most upstream site sampled and was a short distance upstream of the confluence with Bunz Drain, which more than doubles the flow in Cashmere Stream. Site 5 (the most downstream site) was downstream of Miln Drain and the downstream end of the site was located at a Cashmere Stream Care Group clarity monitoring site marker.

Fieldwork was conducted during low flows between 28 April and 5 May 2016, following an unusually dry summer and early autumn.

Figure 1: Cashmere Stream sampling sites. Satellite imagery is from Google.

Table 1: Study site locations. Coordinates mark the downstream end of each 20 m reach.

Site	Easting	Northing	Description
1	1566381	5174057	~10 m upstream of Bunz Drain confluence
2	1566739	5174059	~30 m upstream of Quarry Road Drain confluence
3	1566889	5174049	~200 m upstream of Hoon Hay Valley Stream
4	1567110	5174099	~ 50 m downstream of Hoon Hay Valley Stream
5	1567201	5174532	~ 60 m downstream of Miln Drain
6	1566751	5174042	Quarry Road Drain, ~30 m upstream of Cashmere Stream

Note: Coordinates measured using the New Zealand Transverse Mercator 2000 projection.

2.2. Water Quality

Dissolved oxygen, temperature, pH, and conductivity were measured in the field using a recently-calibrated Horiba U10 water quality meter. Cashmere Stream is classified as a Banks Peninsula class stream under Environment Canterbury's Land and Water Regional Plan (LWRP). Dissolved oxygen data were compared against the LWRP freshwater outcome of a minimum of 90% saturation for Banks Peninsula streams. Temperature data were not compared against guidelines, as they were likely cooler than typical summer temperatures.

2.3. Habitat

Habitat data collection used standard CCC protocols, as described in Boffa Miskell (2015). Following general site selection by CCC, each site comprised a 20 m reach of stream, with habitat measurements either made as an average for the reach, or along each of three transects located 10 m apart along the reach. Any potential barriers to fish passage were noted while walking along the stream.

The percentage contribution of run, riffle, and pool habitat was estimated visually for each 20 m reach. Water velocity was measured using a recently calibrated Pygmy RS current meter at a single point at the centre of each transect. Wetted width was also recorded at each transect.

At each transect, the following bank and riparian habitat measures were recorded for each bank for a 5 metre bank width: surrounding land use, bank material, bank height, bank erosion, bank slope, riparian vegetation, canopy cover, undercut banks, overhanging vegetation and ground cover vegetation. Note that the stream banks were incised and at most transects had a distinct lower and upper bank; to capture this information, bank heights and slopes were recorded for lower and upper banks. A minimum of one and maximum of three bank heights and angles per transect were recorded.

At each transect, the following instream habitat measurements were made at 5 locations per transect, including each bank and mid-channel: water depth, fine sediment depth, embeddedness and substrate composition. Fine sediment depth was measured by pushing a 10 mm diameter steel rod into the substrate until it hit harder substrates underneath. Fine sediment depths greater than 100 cm (the practical limit of measurement) were recorded as 100 cm. Substrate composition was assessed using the following size classes: silt/sand (<2 mm); gravels (2-16 mm); pebbles (16-64 mm); small cobbles (64-128 mm), large cobbles (128-256 mm), boulders (256-4000 mm) and bedrock/concrete/artificial hard surfaces (>4000 mm).

At each of the five locations along each transect, the following data were recorded:

- Macrophyte cover, composition, depth and type (emergent and total)
- Periphyton cover and composition, using categories of Biggs & Kilroy (2000).
- Percentage cover and composition of organic matter.

2.4. Macroinvertebrates

Benthic macroinvertebrates were collected using semi-quantitative protocol C2 of Stark et al. (2001). Briefly, this involves sampling the full range of habitats present at each site using a 500 µm mesh kicknet, with one kicknet sample collected per site. Samples were preserved in 70% ethanol solution and were processed by Ryder Consulting Limited. Invertebrate samples were processed using the full count with subsample option, which is protocol P3 of Stark et al. (2001), and identified to species level where practical.

2.5. Fish

The fish community at each site was sampled using a Kainga EFM 300 backpack electrofishing machine. Following standard CCC protocols (based on those of Joy et al. 2013), the range of habitats present at each site were sampled using a single pass. This was achieved by fishing multiple “lanes”, each approximately 3 m long and 1.5 m wide. Recent macrophyte clearance at Sites 2, 3, 4, and 5 resulted in an area bereft of fish cover in the centre of the channel. Sampling avoided this central area covered in fine sediment and containing minimal habitat, to avoid sampling artificially reduced habitat quality and fish abundance. Stunned fish were either scooped up with a hand net or caught in a stopnet downstream of the catching electrode. Caught fish were transferred to a bucket, then identified, counted, and measured (fork length, mm), before being returned alive to the stream.

2.6. Data Analysis

2.6.1. Habitat

Habitat data collected at five locations per transect were averaged to get a mean value for each transect. Similarly, data collected separately for each bank were averaged to get a mean value per transect. Habitat data from each site were compared statistically using one-way ANOVA, following appropriate data transformations to satisfy assumptions of normality and homogeneity of variances. Lower bank height and water velocity were log-transformed, while lower bank angle and canopy cover were arcsine square-root transformed prior to ANOVA. Post-hoc comparisons of means were conducted using Tukey tests. The Kruskal-Wallis test (a non-parametric equivalent to ANOVA) was used to compare site medians for parameters that did not satisfy ANOVA assumptions of normality, even after data transformation. All statistical tests were undertaken using R statistical software (R Core Team 2016).

Bed cover with filamentous algae and fine sediment (<2 mm diameter) were compared against LWRP freshwater outcomes for Canterbury rivers. Relevant outcomes for Banks Peninsula streams are <20% cover of long filamentous algae and <20% cover of fine sediment. Banks Peninsula streams have no value set for macrophyte cover in the LWRP, so we adopted the target of <30% cover that applies to CCC's stormwater discharge consent for South-West Christchurch (consent number CRC120223). Fine sediment cover was also compared with data collected from the stream in March 2006 as part of the Christchurch River Environment Assessment Survey (CREAS), to assess potential impacts of the recent Canterbury earthquakes on sedimentation.

2.6.2. Invertebrates

The following biological indices were calculated from the raw invertebrate data:

Taxa Richness: The number of different invertebrate taxa (families, genera, species) at a site. Richness may be reduced at impacted sites, but is not a strong indicator of pollution.

%EPT: The percentage of all individuals collected made up of pollution-sensitive Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) taxa. %EPT is typically reduced at polluted sites, and is particularly sensitive to sedimentation.

EPT Taxa Richness: The total number of EPT taxa. EPT richness is typically more negatively affected by pollution than overall taxa richness.

%EPT and EPT Taxa Richness Excluding Hydroptilidae: Both EPT indices were calculated with and without the hydroptilid caddisflies *Oxyethira* and *Paroxyethira*. Unlike most EPT taxa, hydroptilid caddisflies are relatively pollution-tolerant and can be very abundant, skewing EPT indices.

MCI and QMCI: The Macroinvertebrate Community Index and the Quantitative MCI (Stark 1985). Invertebrate taxa are assigned scores from 1 to 10 based on their tolerance to organic pollution. Highest scoring taxa (e.g., many EPT taxa) are the least tolerant to organic pollution. The MCI is based on presence-absence data: scores are summed for each taxon in a sample, divided by the total number of taxa collected, then multiplied by a scaling factor of 20. The QMCI requires either total counts or percentage abundance data: MCI scores are multiplied by abundance for each taxon, summed for each sample, then divided by total invertebrate abundance for each sample. We used calculated site MCI and QMCI scores using the tolerance scores for soft-bottomed streams (Stark & Maxted 2007), as all the sites were dominated by fine sediment. MCI and QMCI scores can be interpreted as per the quality classes of Stark & Maxted (2007), as summarised in Table 2. QMCI scores were also compared against the LWRP freshwater outcome QMCI score of 5 for Banks Peninsula streams.

Table 2: Interpretation of MCI and QMCI scores (from Stark & Maxted 2007).

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

Invertebrate community composition was compared amongst sites using non-metric multi-dimensional scaling (NMDS), a form of ordination. The ordination was based on a Bray-Curtis dissimilarity matrix, using square-root transformed data and the Ecodist package in R. Ordination axis scores were used to correlate community composition with water quality and habitat data (see below).

2.6.3. Fish

Electric fishing data were converted to abundance per 100 m² of stream surveyed. Abundance per 100 m² is a measure of catch per unit of effort (CPUE). Results were compared with recent fishing results reported by Boffa Miskell (2015), unpublished fishing results from January 2016 provided by the Cashmere Stream Care Group (courtesy of David West), and Freshwater Fish Database records. No statistical analyses were conducted, as the data are not quantitative and too few taxa were captured at each site to calculate meaningful fish community indices.

2.6.4. Relationships Amongst Variables

Spearman rank correlation was used to evaluate potential relationships between water quality, site habitat means, invertebrate community indices and invertebrate NMDS axis scores.

3. RESULTS

3.1. Water Quality

At all sites temperatures were cool (<15°C), pH was around neutral (ph=7) to slightly acidic (pH<7), and conductivity moderate (167-275 µS/cm), and within the range of typical values for spring-fed streams in Christchurch (Margetts & Marshall 2015). Dissolved oxygen (DO) saturation was below the LWRP freshwater outcome of 90% saturation at all the sites, with DO particularly low immediately downstream of Bunz Drain confluence (Table 3). Low DO has also been recorded in Cashmere Stream at the CCC water monitoring site at Sutherlands Road, with a median of 44% saturation recorded from monthly samples in 2014 (Margetts & Marshall 2015).

Table 3: Water quality in Cashmere Stream and tributaries, measured on 5 May 2016.

Site	pH	Conductivity (µS/cm)	Dissolved oxygen (mg/L)	Dissolved oxygen (%)	Temperature (°C)	Time (24 hour clock)
1	7.34	253	8.51	81	13.0	0935
Bunz Drain	6.90	275	2.96	28	13.1	0943
2	6.71	223	4.49	43	13.1	0925
3	7.14	223	4.82	46	13.1	0905
4	7.17	223	5.65	53	13.0	0855
5	6.92	230	6.03	57	13.0	0845
6 (Quarry Rd Drain)	7.18	167	8.88	84	12.7	0920

Temperatures would be slightly warmer in summer, but are unlikely to vary greatly with season, due to the dominant spring flow source. However, DO concentrations may fall lower over summer, due to the effect of macrophyte respiration driving down DO overnight. It is therefore likely that DO saturation downstream of Bunz Drain falls below levels recorded in this survey, especially in open sections with high macrophyte cover.

Given the lack of any major industrial waste discharges upstream of Sutherlands Road and lower Bunz Drain, the likely cause of low DO in these waterways is from groundwater inputs with low DO. Several large springs are located in Bunz Drain immediately upstream of Cashmere Stream (Figure 2), and we recorded DO of only 28% saturation at the spring source. This confirms that the source of low DO is from naturally low DO groundwater inputs. DO saturation gradually increased with distance downstream from Bunz Drain, due to diffusion of atmospheric DO. The rate of DO increase would be faster if riffles were present to reaerate the water column.

Figure 2: Bunz Drain immediately upstream of Cashmere Stream, in the vicinity of several large springs.

3.2. Habitat

Representative site photographs are shown in Figure 3 and additional photographs are provided in Appendix 1. Results of all statistical tests are in Appendix 2.

Cashmere Stream is narrow, artificially straight and deeply incised, with steep banks (Figure 3). The stream is generally well-fenced, although cattle have access to the upper reaches near Site 1, where a young bull was observed in the stream bed.

Figure 3: Representative site photographs.

Total bank height varied significantly amongst sites (ANOVA $p<0.05$), ranging from a mean height of 1.6 m at Site 6 to 2.6 m at Site 2. Lower bank angles ranged from 30 degrees to 90 degrees (i.e., vertical), and lower banks were significantly steeper at Sites 4 and 5 than at Sites 1 and 2 (ANOVA $p<0.05$, Table 4). Degree of bank undercutting was positively correlated with lower bank angle ($r_s=0.94$, $p<0.05$), with undercuts becoming deeper as the lower bank angle increased above around 60 degrees (Figure 4). Bank erosion was low overall, due to the combination of good bank cover and stable, spring-fed flows (Table 4).

Stream widths and depths varied significantly amongst sites (Kruskal Wallis $p<0.05$), ranging from a mean width of approximately 1 m wide and depth of 5 cm at Sites 1 and 6, to a width of 4.2 m and depth of 66 cm at Site 3 (Table 4). Water velocities were low overall, but did vary significantly amongst sites (Kruskal Wallis $p<0.05$), and ranged from a mean of 0.11 m/s at Site 6 to 0.28 m/s at Site 2. Instream flow habitat was 100% run at all sites, with minimal instream flow diversity. Greater variation in velocity may occur with moderate macrophyte cover, but CCC contractors had removed macrophytes and fine sediment from Sites 3 to 5 approximately 2 weeks prior to our fieldwork.

The substrate was comprised of fine sediments <2 mm diameter at all sites. Fine sediment depths varied significantly amongst sites (Kruskal Wallis $p<0.05$), ranging from a mean depth of 44 cm at Site 5 to over 100 cm at Site 2 (Table 5). Fine sediment cover exceeded the LWRP freshwater outcome of 20% for Banks Peninsula Streams. CREAS data from 2006 also found this section of Cashmere Stream was covered in fine sediment, suggesting that the current state is not due to earthquake activities in the intervening years. Bed coverage with organic material was generally low and did not differ significantly amongst sites (Kruskal Wallis $p>0.05$). Organic matter was dominated by fine detritus, leaves, and twigs.

There is minimal shade along most of stream, with mean canopy cover of only 22%. However, canopy cover did vary significantly amongst sites (ANOVA $p<0.05$), with Sites 1 and 2 having 40-45% canopy cover, compared to Sites 3, 4 and 5, which all had <10% canopy cover (Table 5). The stream banks were covered in pasture grass and weeds at most sites, but there was less ground cover at Sites 1 and 2, due to higher shading, although this difference was not statistically significant (ANOVA $p>0.05$). There was minimal native vegetation in the riparian zone at most sites, with the vegetation dominated by pasture grass, pasture weeds, and sparse willows and poplars. Site 1 was an exception, as it had a closed canopy of exotic deciduous trees and a ground cover of sparse ferns (Figure 3).

Table 4: Cashmere Stream physical habitat. Data are site means.

Site	Width (m)	Depth (m)	Velocity (m/s)	Lower Bank Height (m)	Lower Bank Angle (degrees)	Total Bank Height (m)	Total Bank Angle (degrees)	Bank undercut (cm)	Bank erosion (%)
1	0.97	0.06	0.19	0.68	44	2.16	53	1	22
2	2.51	0.34	0.28	1.12	49	2.64	45	0	3
3	4.18	0.66	0.19	1.24	73	2.56	64	9	23
4	3.58	0.32	0.20	0.80	89	2.41	61	26	7
5	4.04	0.39	0.20	0.67	84	2.04	51	13	0
6	0.86	0.06	0.11	0.65	56	1.55	53	1	0

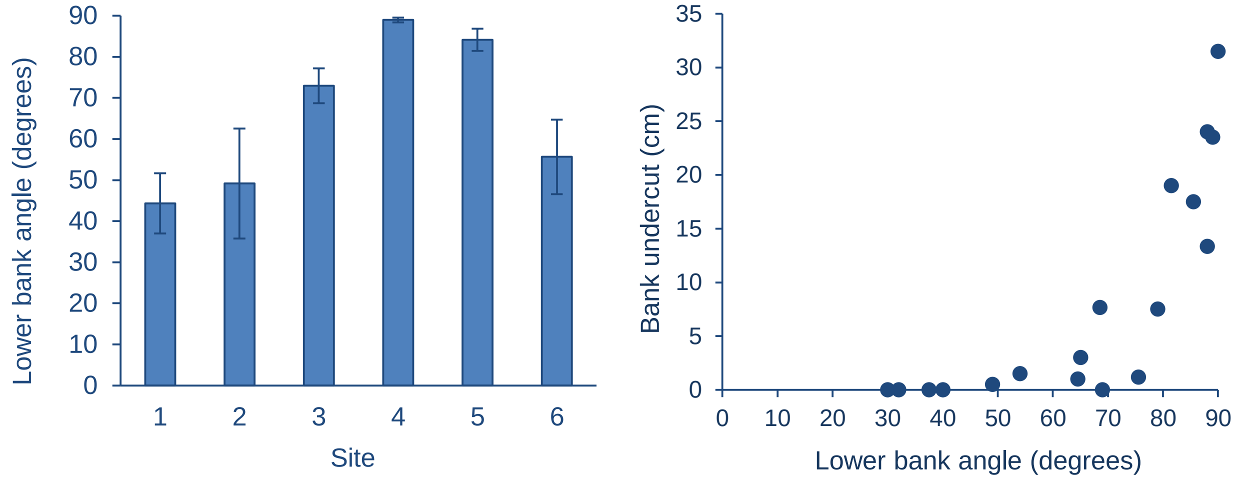

Figure 4: Mean (±1SE) bank angle (left) and the relationship between bank angle and amount of undercutting (right). Data are site means (left) and transect means (right).

Table 5: Bed composition, bank vegetation, and macrophyte cover. Data are site means.

Site	Sand/Silt (%)	Sediment depth (cm)	Organic matter cover (%)	Overhanging vegetation (cm)	Ground cover (%)	Canopy cover (%)	Macrophyte cover (%)
1	100	49	26	0	27	45	1
2	98	100	17	10	72	40	16
3	99	96	7	18	100	3	20
4	100	92	15	14	98	8	34
5	100	44	14	13	97	8	39
6	100	63	10	23	98	30	75

Macrophyte cover differed significantly amongst sites (ANOVA $p<0.05$), with mean cover ranging from 1% at Site 1 to 75% at Site 6 (Figure 5). Macrophyte cover was not correlated with canopy cover ($r_s=-0.46$, $p>0.05$), likely because Cashmere Stream had been cleared of macrophytes approximately 2 weeks prior to our fieldwork. Macrophyte cover exceeded the South-West discharge consent target of 30% cover at Sites 4, 5, and 6, and was greatest at Quarry Road Drain, where macrophyte clearance had not occurred (Figure 5). The lowest macrophyte cover was at Site 1, which was the most shaded site and where no macrophyte clearance had occurred.

Macrophytes were dominated by common exotic species at all sites. Canadian pondweed (*Elodea canadensis*) and curly pondweed (*Potamogeton crispus*) – both exotic species – were the most abundant submerged species, although native milfoil (*Myriophyllum propinquum*) was also common. Watercress (*Nasturtium officinale*) is an exotic species and was the dominant emergent macrophyte. Two floating native species – duckweed (*Lemna* sp.) and the fern *Azolla rubra* – were sparsely represented at most sites. *Elodea canadensis* was particularly abundant at Site 6, which had not been cleared of macrophytes. *Elodea* *canadensis* and *Potamogeton crispus* were likely widespread throughout the study area prior to waterway clearance, based on the observation of broken stems in the stream bed, and previous observations downstream of our study area (Boffa Miskell 2015).

Periphyton was either absent or very uncommon at all sites, likely due to the dominance of fine bed sediments and macrophytes throughout the study area. Periphyton cover therefore complied with the LWRP objective of less than 20% cover with filamentous algae.

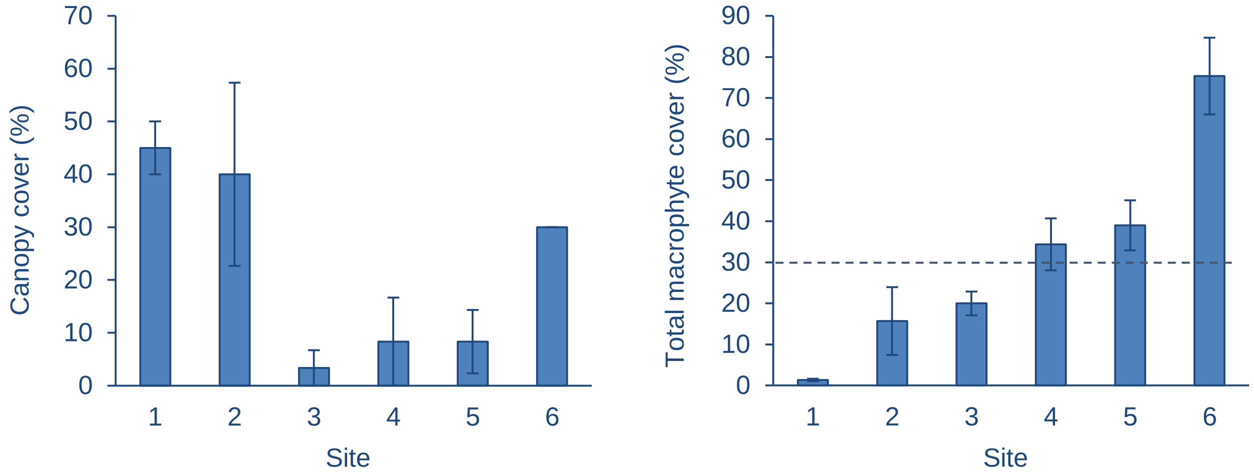

Figure 5: Mean (±1SE) canopy cover (left) and macrophyte cover (right) at each site. Dashed horizontal line is the South-West discharge consent target of 30% cover.

The only potential barrier to fish passage observed was the pipe culvert under Sutherlands Road (Figure 6). This culvert was not inspected during the site visit, as it is upstream of the study reach. However, we conducted a follow-up inspection of the culvert in July and we observed that the culvert is steep and has shallow water depths. In addition, we understand that the culvert may become perched during low flow (pers. comm., Dave West, Cashmere Stream Care Group), although it was not perched during our site visit. The steep gradient and shallow water depth in the culvert could present an obstacle to upstream migrating fish species with poor climbing abilities, such as inanga, as well as larger-bodied fish, such as brown trout. If it is perched during low flows, then that would present an additional obstacle. However, eels would readily navigate the culvert, as they are relatively strong climbers. Fish species composition in relation to the culvert is discussed in Section 3.4 below.

Figure 6: Sutherland Road culvert. Photograph taken on 14 July 2016 following recent rain.

3.3. Macroinvertebrates

The invertebrate community was numerically dominated by pollution-tolerant taxa at all sites, particularly the common mudsnail *Potamopyrgus antipodarum* (Mollusca) and the amphipod *Paracalliope fluviatilis* (Crustacea). Together these two species comprised at least 94% of the total number of individuals caught from each site (Figure 7). Other common but less abundant taxa included ostracods, chironomid midge larvae, and other snail species. Mayflies and stoneflies were absent from all sites; this is typical for Canterbury lowland streams, due to the long history of agricultural and urban landuse. The most abundant caddisfly taxa present were the pollution-tolerant algal piercers, *Oxyethira* and *Paroxyethira*. See Appendix 3 for a complete list of all invertebrates collected.

Three koura were collected from Site 5 during electrofishing. They were all small specimens, ranging in size from 28 to 32 mm (orbit-carapace length – measured from behind the eye to the end of the carapace along the top and centre of the back). Koura are valued mahinga kai and are also of conservation value, due to their “At Risk – Declining” conservation status (Grainger et al. 2014).

Taxa richness ranged from 13 taxa at Site 3 to 26 taxa at Site 5 (Table 6). The notably higher taxa richness at Site 5 likely reflected the overall greater number of individuals caught, as taxa richness increases with abundance. As indicated in Section 2.4, invertebrate taxa richness is not a particularly good indicator of ecosystem health, because moderately degraded sites can have quite high taxa richness. EPT taxa richness and %EPT were both low at all sites (Table 6), reflecting the dominance of snails and crustaceans.

MCI scores were low at all sites, ranging from 69 at Site 1 to 81 at Site 2, and were indicative or poor to fair water quality or habitat. QMCI scores were also indicative of poor conditions at all sites, and ranged from 2.19 at Site 1 to 3.91 at Site 2 (Figure 8). At all sites QMCI scores were well below the LWRP freshwater outcome QMCI score of 5 for Banks

Peninsula streams. Low MCI and QMCI scores reflect the dominance of pollution-tolerant taxa at all sites.

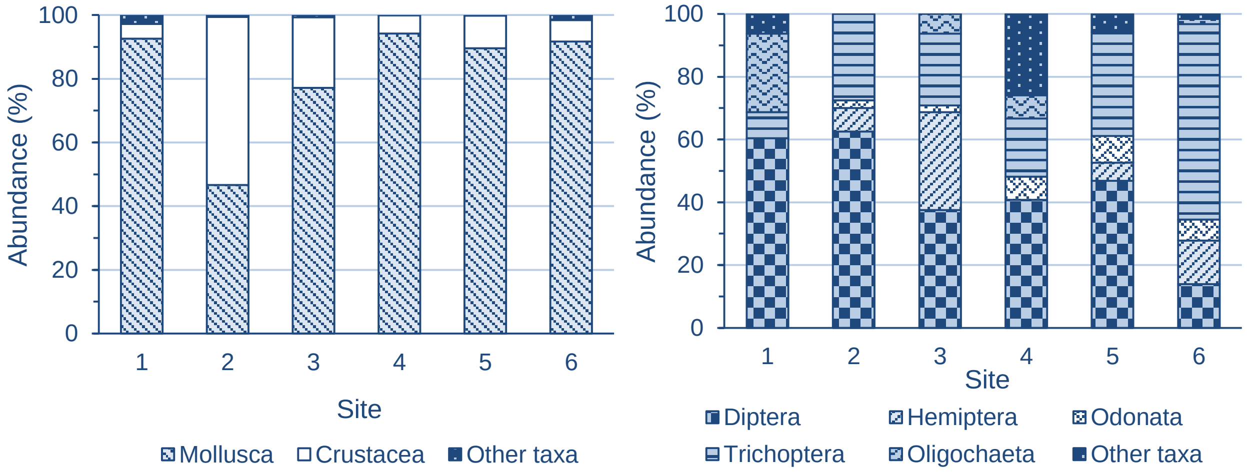

Figure 7: Relative abundance of all invertebrate taxa (left) and all taxa excluding Mollusca and Crustacea (right).

Ordination of the invertebrate community yielded a two-dimensional solution with low stress (0.10), indicating a good relationship between the original dissimilarity matrix and distance in ordination space (Clarke 1993). No individual invertebrate taxa were significantly correlated with either ordination axis ($r_s<0.89$, $p>0.05$). Total invertebrate abundance was significantly correlated with Axis 2 ($r_s=0.94$, $p<0.05$); no other invertebrate or habitat metric was significantly correlated with either axis. The lack of correlation of habitat or invertebrate data with ordination axis scores was likely due to a combination of the low number of data points being compared (and hence weak statistical power), and the very similar invertebrate community composition at all sites, with all sites dominated by snails and amphipods.

Table 6: Invertebrate community indices.

Site	Total abundance	Taxa richness	EPT richness	EPT richness (excl Hydroptilidae)	%EPT abundance	MCI	QMCI
1	1,727	16	1	1	0.2	69	2.19
2	7,367	14	3	2	0.1	81	3.91
3	7,032	13	2	1	0.2	77	2.73
4	53,058	17	2	2	0.0	79	2.28
5	86,728	26	6	5	0.1	76	2.43
6	15,776	19	4	2	1.0	67	2.33

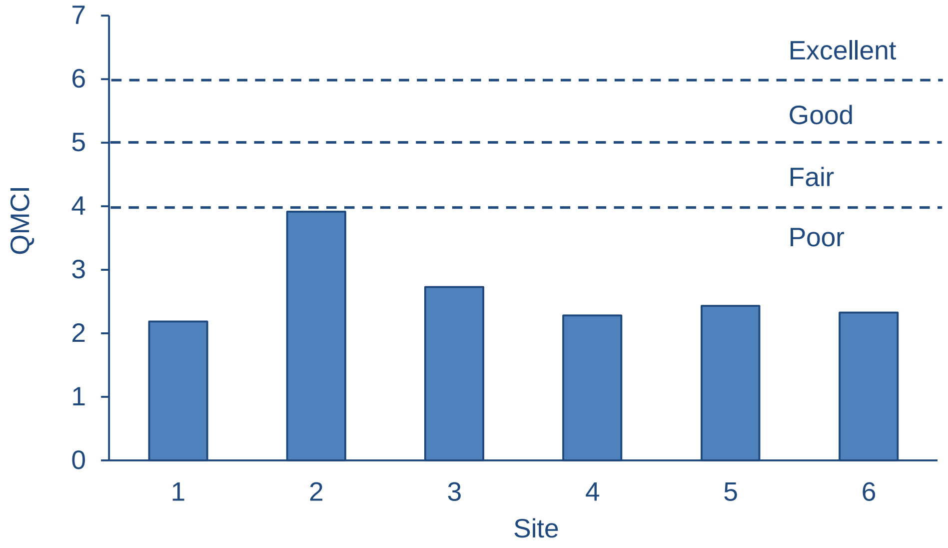

Figure 8: Invertebrate QMCI scores. Dashed lines indicate quality classes from Stark & Maxted (2007).

Boffa Miskell (2015) reported similar invertebrate community composition in Cashmere Stream, with a QMCI score of 4.0 upstream at Sutherlands Road and a score of 2.9 downstream at Penruddock Rise. Most of the other invertebrate metrics from this survey were comparable to those recorded by Boffa Miskell (2015). The exception was taxa richness at Site 5, where we collected a total of 27 taxa, compared with a maximum of 16 taxa recorded by Boffa Miskell at their Sutherlands Road site.

Koura have previously been recorded from Cashmere Stream a short distance downstream of Bunz Drain, and downstream of our study area, near Dunbars Drain and Hendersons Drain (Freshwater Fish Database Records). Although koura were only detected at Site 5 in this survey, they are likely present in low numbers throughout the study area, wherever there is sufficient habitat and shelter from regular weed clearance.

Kākahi (freshwater mussels) have been recorded from the lower reaches of Cashmere Stream (Burdon & McMurtie 2009) and empty mussel shells have also been found upstream at Sutherlands Road (Boffa Miskell 2015), but previous surveys found no kākahi at the sites we studied (Burdon & McMurtie 2009). Kākahi have an “At Risk – Declining” conservation status (Grainger et al. 2013) and they tend to be less common in urban streams than in rural or native forest streams. Kākahi may be present in the section of Cashmere Stream sampled, but they are easily missed by standard invertebrate sampling methods and were not detected during this survey. The soft bed sediments present and regular mechanical clearance of macrophytes may also limit the habitat available for kākahi.

3.4. Fish

Shortfin eel (*Anguilla australis*) was the most abundant fish species, and they were caught at all sites (Figure 9). Upland bullies (*Gobiomorphus breviceps*) were also relatively common and found at all sites. A single longfin eel (Anguilla dieffenbachii) was found at Site 1 and a single giant bully (*Gobiomorphus gobioides*) was collected at Site 5. A large brown trout (*Salmo trutta*) at least 300 mm long was also observed (but not caught) immediately upstream of Site 3. Native inanga, or whitebait (*Galaxias maculatus*), and common bullies (*Gobiomorphus cotidianus*) are also likely to be present in low numbers, based on Freshwater Fish Database records and recent surveys in Cashmere Stream upstream and downstream of the sites we sampled (Boffa Miskell 2015; Cashmere Stream Care Group unpublished data). Bluegill bully (*Gobiomorphus hubbsi*) have been recorded from sites further downstream, where coarse sediments are present (Taylor & Blair 2012), but they are unlikely to occur in the reaches we sampled, due to the dominance of fine sediments.

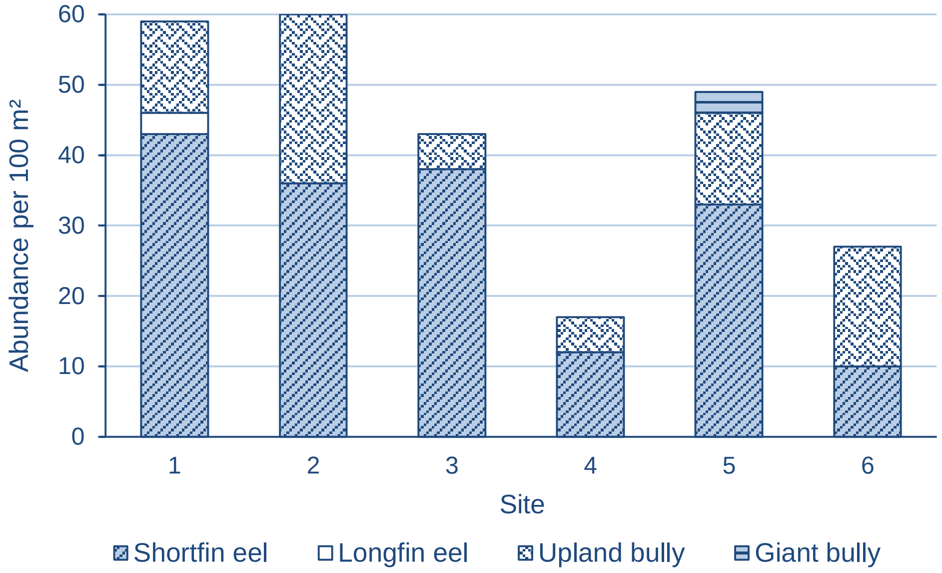

Figure 9: Fish species and abundance caught from the six sampling sites.

Shortfin eels, upland bullies, and common bullies are all common native species. Shortfin eel, longfin eel, and inanga are valued mahinga kai, while longfin eel and inanga are also of conservation interest, as they have an “At Risk – Declining” status (Goodman et al. 2014). Brown trout support a valued recreational fishery nationally, although the Cashmere Stream fishery is likely of local, rather than regional or national value, due to the close proximity of numerous trout streams nearby (e.g., the Selwyn River, Harts Creek, and the Kaiapoi River).

Eels, common bully, giant bully, and inanga all migrate between freshwater and the sea to complete their life cycle. We recorded a wide range of sizes for both shortfin eels and upland bullies, indicating good recruitment and access to and from the sea for eels (Table 7). The largest fish caught was a 900 m long shortfin eel at Site 5, although most shortfins caught were around 200-400 mm long. Fish community composition and abundance were likely affected by the recent drain clearance activities, as mechanical drain clearance can reduce native fish abundance by 60% (Greer et al. 2012).

Based on data from Boffa Miskell (2015) and the Cashmere Stream Care Group, fish composition is similar upstream and downstream of Sutherlands Road, being dominated by shortfin eel and upland bully, with inanga and common bully present in lower numbers. However, no brown trout or giant bully have been recorded upstream of Sutherlands Road, which suggests the culvert may restrict their upstream passage.

Table 7: Mean length (range in brackets) of fish caught from the six sampling sites. No size range is shown for longfin eel and giant bully, because only one individual was caught of each species.

Site	Shortfin eel	Longfin eel	Upland bully	Giant bully
1	162 (112-345)	378	40 (36-43)	
2	175 (111-302)		47 (32-62)	
3	199 (130-306)		53 (36-80)	
4	253 (152-404)		66 (59-72)	164
5	252 (92-900)		43 (42-67)	
6	201 (153-201)		41 (30-62)	

4. DISCUSSION

All of the Cashmere Stream sites surveyed had degraded habitat conditions, with little variation amongst or within sites. With the exception of Site 1, all sites lacked riparian trees and shrubs, resulting in a lack of stream shade, organic matter inputs, and buffering against adjacent landuse. The stream channel is very straight, resulting in a complete lack of variation in channel form and instream habitat variation. While fencing is generally adequate, cattle have access to the upper reaches of the stream near Site 1, which is associated with some bank trampling and sedimentation.

Regular mechanical removal of aquatic macrophytes and fine sediment likely has a significant impact on fish abundance and diversity (Greer et al. 2012). The dominance of pollution-tolerant invertebrate species and shortfin eels partly reflects the lack of stony substrates and prevalence of fine bed sediments, and also likely reflects the overall lack of aquatic habitat.

While bank undercuts currently provide fish habitat at some sites, they are also associated with bank erosion and sedimentation, which degrade water quality and habitat. Reduced bank angles coupled with the provision of bank and instream fish cover (e.g., logs, boulders, and overhanging vegetation) would be a more sustainable option. Increased habitat diversity would increase the range of habitats for different invertebrate and fish species to colonise.

Low DO from Bunz Drain springs may be limiting for sensitive fish species such as brown trout. Native fish species such as eels and inanga are less likely to be affected, as they are relatively tolerant of low DO (Dean & Richardson 1999). There is little known about the DO tolerances of New Zealand freshwater invertebrates, although riffle-dwelling EPT taxa are likely more sensitive to low DO (Davies-Colley et al. 2013). Although Bunz Drain contributed low DO to Cashmere Stream, the large springs present near Cashmere Stream are of ecological interest. This is because springs are often considered biodiversity hotspots, because they harbour a unique invertebrate fauna dominated by specialist groundwater species (Death et al. 2004). Springs are also of cultural significance to Maori.

The existing culvert at Sutherlands Road appears to prevent upstream passage by brown trout and may also restrict upstream passage by poor climbing native species, such as inanga. If the culvert is upgraded (to better convey high flows) and fish passage improved, trout could pass upstream into habitat that is currently dominated by native species. If a culvert upgrade is required, then consideration should be given to excluding trout from upstream reaches.

Despite its degraded aquatic and riparian habitat, Cashmere Stream does support a number of ecologically significant aquatic values. The key aquatic values of Cashmere Stream include:

- **Longfin eel, inanga, and koura** – due to their "At Risk – Declining" status and mahinga kai value.
- **Minimal urban landuse** – rural streams lack the pressures of urban landuse, particularly stormwater impacts on hydrology and water quality.
- **Migratory corridor** – the lack of any major fish barriers downstream of Sutherlands Road allows migratory fish species passage to and from the sea. The Sutherlands Road culvert appears to exclude brown trout from upstream reaches, meaning that native species upstream of the culvert are protected from trout predation.
- **Reasonable flow** – good flows downstream of Bunz Drain provide adequate depth for large fish, such as adult eels and brown trout.
- **Bunz Drain Springs** – springs are often biodiversity hotspots and they are culturally significant. The deep springs in Bunz Drain are notable because of their large size.

5. RESTORATION RECOMMENDATIONS

5.1. Restoration Goals

Any restoration project should start with a clear goal. It is impractical to restore Cashmere Stream to its historic wetland condition, as that would require a greater amount of space than is available, whilst maintaining the existing level of flood mitigation downstream. At the other end of the habitat spectrum, we also consider it impractical to create a gravel-bottomed stream, as fine sediments will likely rapidly accumulate and bury the gravels, due to the lack of gradient, water velocity and flushing flows. Although much of the habitat would naturally have been low gradient and dominated by soft sediments, naturally gravel-dominated streams elsewhere in Christchurch have become increasingly rare, due to urbanisation, historically inadequate stormwater treatment, and associated sedimentation. We therefore suggest that the restored stream should include a mix of deeper, low gradient pool habitats for larger fish such as eels and trout, and steeper gravel/cobble habitat for juvenile eels and bullies.

For Cashmere Stream, we suggest the broad restoration goal should be increased diversity and abundance of native plants and fish. The aim should be to increase fish diversity and koura abundance through the provision of increased habitat diversity, protecting (and possibly enhancing) water quality, and reducing disturbance from regular macrophyte and sediment removal.

Target aquatic species for habitat restoration may include:

- Bluegill bully and juvenile longfin eel – which prefer silt-free gravel riffles
- Inanga and shortfin eel – which prefer deeper, sluggish run habitat and pools
- Koura – which prefer lots of bank and instream cover
- Kākahi – which may be limited by fine sediments and regular macrophyte clearance

5.2. Restoration Actions

We recommend the following actions to meet the restoration goals:

- **Best practice stormwater treatment.** We understand CCC will be using detention ponds and wetlands to treat stormwater from new residential areas. This is essential for preventing potential impacts on stream water quality and hydrology.
- **Treatment of loess sediment from hills.** Fine loess soils remain in suspension for a long time. One risk of stormwater detention is that the fine sediments remain in suspension in the ponds and are slowly released into the stream, creating a “long tail” of turbidity. The stormwater treatment design should therefore include removal of fine loess sediments from suspension.
- **Create a new meandering channel alignment.** This will create instream flow diversity and aquatic habitat for invertebrates and fish to colonise. It would also allow for the channel works to be undertaken outside of flowing water, reducing the risk of downstream sediment impacts. Batter the banks back to reduce bank angles and avoid bank undercutting and erosion.
- **No net loss of flowing habitat.** The aim of the restoration should be to improve habitat quality and avoid any loss of habitat. We understand that Quarry Road Drain flows through the middle of the proposed stormwater treatment site. We recommend realigning Quarry Road Drain rather than piping it, because it does support aquatic values and these should not be lost through piping.
- **Provide for low flow habitat.** Create a narrow, v-shaped low flow channel to provide adequate aquatic habitat for fish and invertebrates during low flows at the base of Quarry Road Drain and Cashmere Stream upstream of Boyz Drain.
- **Create a mix of pool, riffle and run habitat.** This will create habitat diversity that is now lacking. Deeper pools would be favoured by larger eels, trout and inanga, while gravel/cobble riffles would provide habitat for juvenile longfin eels and bullies. Riffle sections will need to be sufficiently narrow and steep to prevent fine sediment burying the coarse gravels and cobbles.
- **Pools for sediment trapping.** Pools are natural sediment traps, so they should be placed upstream of riffles to help settle-out fine sediments. Pools could be placed in locations that are accessible for diggers to occasionally remove built up sediment deposits.

- **Snags and boulders.** The addition of tethered logs, root-wads, and boulders to the channel would provide cover and habitat for a range of native fish and koura. Boulders or open-ended pipes should be placed below the water line of steeper banks to provide fish and koura habitat.
- **Strategic riparian plantings.** Native vegetation should be planted up to the water's edge, to shade-out nuisance macrophytes and provide habitat for fish, koura, and other invertebrates. It is particularly important to have full canopy cover to prevent periphyton growth in the coarse riffle sections, as riffle-dwelling invertebrate and fish species do not tolerate heavy periphyton growth. Increased stream shading should reduce the need for regular drain clearance, while plants on the lower banks will overhang the water and provide habitat and localised shading.
- **Protect Bunz Drain springs.** These impressive springs are the major source of baseflow in Cashmere Stream below Bunz Drain, so it is important that any channel realignment captures the springs' flow. The springs should also be protected because of their biodiversity and cultural value.
- **Place a riffle downstream of Bunz Drain.** Placing a shallow riffle immediately downstream of Bunz Drain would help reaerate the water, increasing oxygen concentrations to levels suitable for sensitive invertebrate and fish species.
- **Protect Fish Passage.** If the existing Sutherlands Road culvert is upgraded, the design should consider excluding brown trout, while maintaining or enhancing upstream access for inanga and common bully. This may be possible using the likes of mussel spat ropes laid along the culvert (David et al. 2014). Cashmere Stream Care Group should be consulted regarding culvert design, as they have undertaken restoration work upstream and are interested in keeping the upper reaches trout-free.
- **Fish, koura & kākahi salvage.** All fish should be removed from the affected length of Cashmere Stream and Quarry Road Drain prior to flow being diverted to the new channel alignment. Searches should also be made for koura and kākahi using appropriate methods, due to their conservation value and cryptic nature.
- **Monitor success.** Ecological monitoring should be undertaken following completion of the new channel, to evaluate the success of the restoration works. Monitoring will need to occur over a number of years, to allow an adequate length of time for biological communities to colonise and establish in the new habitat.

6. REFERENCES

Biggs, B. J. F., and Kilroy, C. (2000). Stream periphyton monitoring manual. Prepared for the Ministry for the Environment. NIWA, Christchurch.

Boffa Miskell Limited (2015). Aquatic ecology of sites within the Heathcote, Estuary and Coastal, and Avon SMP catchments: informing the comprehensive discharge consent. Report prepared by Boffa Miskell Limited for Christchurch City Council, August 2015.

Burdon, F., and McMurtrie, S. Baseline survey of freshwater mussels (kakahi) in Cashmere Stream. Report prepared by EOS Ecology for Christchurch City Council and Environment Canterbury, July 2009.

Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18, 117–143.

David, B., Hamer, M., Tonkin, J., Bourke, C. (2014). Appropriate use of mussel spat ropes to facilitate passage for stream organisms. Waikato Regional Council Technical Report 2014/29, March 2014.

Davies-Colley, R., Franklin, P., Wilcock, B., Clearwater, S., and Hickey, C. (2013). National objectives framework - temperature, dissolved oxygen and pH. Proposed thresholds for discussion. Report prepared by NIWA for the Ministry for the Environment, November 2013.

Dean, T. L., and Richardson, J. (1999). Responses of seven species of native freshwater fish and a shrimp to low levels of dissolved oxygen. New Zealand Journal of Marine and Freshwater Research 33, 99–106.

Death, R., Barquin, J., and Scarsbrook, M. (2004). Biota of cold-water and geothermal springs. In ‘Freshwaters of New Zealand’. Edited by J. Harding, P. Mosley, C. Pearson, and B. Sorrell, Caxton Press, Christchurch.

Goodman, J. M., Dunn, N. R., Ravenscroft, P. J., Allibone, R. M., Boubee, J. A. T., David, B. O., Griffiths, M., Ling, N., Hitchmough, R. A., and Rolfe, J. R. (2014). Conservation status of New Zealand freshwater fish, 2013. New Zealand Threat Classification Series 7, Department of Conservation.

Grainger, N., Collier, K., Hitchmough, R., Harding, J., Smith, B., and Sutherland, D. (2014). Conservation status of New Zealand freshwater invertebrates, 2013. New Zealand Threat Classification Series 8, Department of Conservation, Wellington.

Greer, M. J. C., Closs, G. P., Crow, S. K., and Hicks, A. S. (2012). Complete versus partial macrophyte removal: the impacts of two drain management strategies on freshwater fish in lowland New Zealand streams. Ecology of Freshwater Fish 21, 510–520.

Joy, M., David, B., and Lake, M. (2013). New Zealand freshwater fish sampling protocols. Part 1 - Wadeable rivers and streams. The Ecology Group - Institute of Natural Resources, Massey University, Palmerston North.

Margetts, B., and Marshall, W. (2015). Surface water quality monitoring report for Christchurch City waterways: January - December 2014. Christchurch City Council Report, April 2015.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Stark, J. D., Boothroyd, I. K. G., Harding, J. S., Maxted, J. R., and Scarsbrook, M. R. (2001). Protocols for sampling macroinvertebrates in wadeable streams. Ministry for the Environment, Wellington.

Stark, J. D., and Maxted, J. R. (2007). A biotic index for New Zealand’s soft-bottomed streams. New Zealand Journal of Marine and Freshwater Research 41, 43–61.

Taylor, M., and Blair, W. (2012). Halswell and Heathcote aquatic values; selected aspects; monitoring round # 4. Report prepared by Aquatic Ecology Ltd for Christchurch City Council, September 2012.

APPENDIX 1: SITE PHOTOGRAPHS

Figure 10: Site 1, view upstream from the bottom of the reach.

Figure 11: Site 1, view downstream from top of reach.

Figure 12: Site 2, view upstream from bottom of the reach.

Figure 13: Site 2, view downstream from top of reach.

Figure 14: Site 3, view upstream from bottom of the reach.

Figure 15: Site 3, view downstream from top of the reach.

Figure 16: Site 4, view upstream from bottom of the reach.

Figure 17: Site 4, view downstream from top of the reach.

Figure 18: Site 5, view upstream from bottom of the reach.

Figure 19: Site 5, view downstream from top of the reach.

Figure 20: Site 6, view upstream from bottom of the reach.

Figure 21: Site 6, view downstream from top of the reach.

APPENDIX 2: STATISTICS SUMMARY

Parameter	Statistical test	Transformation	ANOVA P	Post-hoc comparisons
Lower bank height	ANOVA	Log_{10}	0.3160	
Total bank height	ANOVA	No	<0.0001	6 5 1 4 3 2
Lower bank angle	ANOVA	Arcsine square root	0.0009	1 2 6 3 5 4
Total bank angle	ANOVA	No	0.0326	2 6 5 1 4 3
Canopy cover	ANOVA	Arcsine square root	0.0146	3 4 5 6 2 1
Bank undercut	Kruskal Wallis	No	0.0329	Not significant
Overhanging vegetation	Kruskal Wallis	No	0.0306	1 2 5 4 3 6
Ground cover	Kruskal Wallis	No	0.1426	
Bank erosion	Kruskal Wallis	No	0.2370	
Width	Kruskal Wallis	No	0.0100	Not significant
Depth	Kruskal Wallis	No	0.0073	1 6 4 2 5 3
Velocity	ANOVA	Log_{10}	0.0122	6 3 1 5 4 2
Fine sediment depth	Kruskal Wallis	No	0.0369	Not significant
Fine sediment cover	Kruskal Wallis	No	0.0889	
Macrophyte cover	ANOVA	No	<0.0001	1 2 3 4 5 6
Organic matter cover	Kruskal Wallis	No	0.1524	

APPENDIX 3: RAW INVERTEBRATE DATA AND INDICES

TAXON	MCI-sb	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
ACARINA	5.2	2					
COLEOPTERA							
Liodessus plicatus	4.9	1			5	2	1
COLLEMBOLA	5.3				2		3
CRUSTACEA							
Ostracoda	1.9	59	3	275	203	458	55
Paracalliope fluviatilis	5.5	20	3,890	1,284	2,816	8,369	1,008
Paratya curvirostris	3.6			1	3	3	
DIPTERA							
Austrosimulium australense-group	3.9						5
Chironomus species	3.4	2			1	12	
Corynoneura scutellata	1.7	2					
Ephydridae	1.4		2	1	2	1	3
Hexatomini	6.7		1				
Muscidae	1.6	1					
Orthocladiinae	3.2	11	2	13	3	57	26
Paradixa species	8.5		15	3	4	4	
Paralimnophila skusei	7.4			1	1		
Polypedilum species	8	5	5				
Sciomyzidae	3	1				4	1
Tanypodinae	6.5					4	
Zelandotipula species	3.6	7					
HEMIPTERA							
Microvelia macgregori	4.6		3	15		8	34
Sigara species	2.4					2	1
LEPIDOPTERA							
Hygraula nitens	1.3					5	
MOLLUSCA							
Gyraulus corinna	1.7					10	
Lymnaeidae	1.2	1					
Physella (Physa) acuta	0.1	2	11		10	41	6
Potamopyrgus antipodarum	2.1	1,597	3,423	5,424	49,994	77,569	14,431
Sphaeriidae	2.9				5	103	24
NEMATODA	3.1					2	
ODONATA							

TAXON	MCI-sb	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Xanthocnemis zealandica	1.2		1	1	2	15	17
OLIGOCHAETA	3.8	12		3	2		4
PLATYHELMINTHES	0.9					1	
TRICHOPTERA							
Hudsonema amabile	6.5		2		1	19	6
Oecetis unicolor	6.8					12	
Oxyethira albiceps	1.2		4	7		2	105
Paroxyethira hendersoni	3.7						44
Polyplectropus puerilis	8.1					3	
Psilochorema bidens	7.8					4	
Triplectides cephalotes	5.7						2
Triplectides obsoletus	5.7	4	5	4	4	18	
Total abundance		1,727	7,367	7,032	53,058	86,728	15,776
Taxa richness		16	14	13	17	26	19
EPT richness		1	3	2	2	6	4
EPT richness (excl Hydroptilidae)		1	2	1	2	5	2
%EPT richness		6	21	15	12	23	21
%EPT richness (excl Hydroptilidae)		6	14	8	12	19	11
MCI-sb		69	81	77	79	76	67
QMCI-sb		2.19	3.91	2.73	2.28	2.43	2.33
%EPT abundance		0.2	0.1	0.2	0.0	0.1	1.0
%EPT (excl Hydroptilidae)		0.2	0.1	0.1	0.0	0.1	0.1