Halswell River sediment and aquatic ecology survey

Aquatic Ecology Technical Report
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Boffa Miskell

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Cover photograph: Halswell River at Wroots / Halswell Road, Boffa Miskell 2016

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Executive summary

The Christchurch City Council commissioned Boffa Miskell Limited to conduct an aquatic ecology survey of five sites within the Halswell River catchment and the South-West Stormwater Management Plan area. This survey was designed to describe the current ecological condition of these waterways, to compare the current conditions to relevant guidelines and water quality objectives, and investigate if conditions may have changed over time.

Riparian and in-stream habitat conditions, sediment contaminant concentrations, and the macroinvertebrate and fish communities were surveyed at five sites located in the Halswell River catchment in March 2016.

The basic water-quality parameters of pH, dissolved oxygen, conductivity and temperature were within ranges expected in a spring-fed urban environment during base-flow conditions. In-stream and riparian conditions, although variable among sites, were generally degraded often with low substrate indexes (indicating stream-bed substrates dominated by finer particles and generally lacking in boulders and large cobbles). Very little shading was present at many sites, and channels were modified with limited in-stream habitat heterogeneity. Macrophyte and filamentous algal cover was generally low and the majority of sites were below the LWRP guidelines for urban spring-fed systems.

The contaminant concentrations in sediment collected from each site were similar to the concentrations found previously and generally were well below the ANZECC guidelines, with the exception of lead and zinc in Halswell River CC limits and Nottingham Stream, respectively.

The macroinvertebrate communities were dominated by taxa typical of lowland urban waterways, with only a few representatives from the pollution-sensitive or “clean-water” EPT taxa (i.e. caddisflies) present. Although there were some subtle differences in macroinvertebrate community composition, the community found in this study was similar to that found in 2011.

The fish communities were depauperate, with species richness generally around three to six fish species present at a site. Nevertheless, the species composition found in this study was similar to that found in 2011. The most notable difference was that many more longfin eels were found in this study, than in 2011.

Furthermore, kōura (freshwater crayfish, a macroinvertebrate species which is often captured during electric-fishing surveys) were abundant in Creamery Stream in 2004 but was not found when the site was resurveyed in 2011 after the Canterbury earthquakes. Kōura were not found in Creamery Stream in this study, so are unlikely to have recolonised this waterway.

A further noteworthy finding was that when sites were ranked according to: a) sediment contaminant concentrations; and b) the four biotic indices, Site 3: Knights Stream and Site 2: Creamery Stream were found to be the best sites overall. Site 1: Nottingham Stream was scored as the worst site for both sediment contaminant concentrations and macroinvertebrate biotic indices.

This ecological assessment indicated that the waterways within the Halswell River catchment and the South-West Stormwater Management Plan area were generally of poor ecological health. Nevertheless, it is important to remember that sites did provide habitat for ecologically important native macroinvertebrate and fish species. All sites supported longfin eels, an “at risk, declining” native freshwater fish species, while inanga (also “at risk, declining”) were present at one site.

The findings of this work reiterate the need for a multi-faceted approach to catchment management. Areas of greatest ecological health need to be maintained through appropriate management activities, and more degraded areas, with lower ecological health, may also be improved over time through more intensive management of stormwater and contaminated sediments, and enhancements of in-stream and riparian habitat.

Background

The Halswell River / Huritini catchment is around 190 km^2, located to the south of Christchurch, originating from the Port Hills in the east and small urban headwater tributaries to the north. The Halswell River / Huritini then flows through flat, predominantly rural, land until it discharges into Lake Ellesmere / Te Waihora.

The Halswell River catchment is predominantly rural, however, with increasing residential development of the outlying areas of Christchurch City, much of the land is changing from rural to urban. The effects of urbanisation on freshwater ecosystems is well understood, whereby an increase in impervious surfaces in the catchment results in generally lower, but flashier, flows and pollutants and sediments readily transported into waterways.

In 2011, the CCC was granted a global consent for stormwater discharge and associated stormwater mitigation measures for the whole of south-west Christchurch, including the upper Halswell River / Huritini catchment[1]. Under this SWSMP (CRC120223), the CCC is required to monitor selected freshwater sites every five years within the Halswell River catchment. This study is the first time these sites have been monitored under this consent, however, some of the sites have been previously monitored as part of other programmes (Kingett Mitchell Ltd 2005; EOS Ecology 2011; Aquatic Ecology Ltd 2012).

Scope

The CCC commissioned Boffa Miskell to conduct an aquatic ecology survey of five sites within the Halswell River catchment, which lies within the South West Stormwater Management Plan (SWSMP) area. This survey was designed to investigate the effects of stormwater on the aquatic ecology of the waterways by:

- Describing the current ecological condition of these waterways, including riparian and in-stream habitat conditions, sediment quality, and the macroinvertebrate and fish communities;
- Comparing current conditions against the SWSMP consent surface water quality objectives; Environment Canterbury's Land and Water Regional Plan (LWRP) water quality standards and freshwater outcome guidelines, and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000);
- Comparing trends over time by assessing the current conditions against the results of previous survey (Kingett Mitchell Ltd 2005; EOS Ecology 2011; Aquatic Ecology Ltd 2012); and
- Discussing overall ecological health of the sites and recommending how to improve the health, particularly where:
    - Water quality objectives have not been met; and
    - Any significant long-term trends have been observed.

[1] The lower Halswell River / Huritini is managed by the Selwyn District Council.

Methods

Site locations

The CCC provided Boffa Miskell with northing and easting co-ordinates for 5 sites (shown in Table 1) located in the Halswell River catchment and within the SWSMP.

Table 1. Freshwater ecology survey sites within the Halswell River catchment and the South-West Stormwater Management Plan (SWSMP).

Site number	Site name	Easting	Northing
S1	Nottingham Stream at O'Halloran Drive	2475062	5735092
S2	Creamery Stream at Sabys Road	2474273	5734813
S3	Knights Stream at 162 Whincops Road	2472634	5736096
S4	Halswell River at Christchurch City limits	2475268	5731707
S5	Halswell River at Wroots/Halswell Roads	2474357	5734086

The co-ordinates (northing and easting) of each site (as provided by the CCC to Boffa Miskell, Table 1) were loaded into Avenza pdf maps using ArcGIS, and using a geo-referenced pdf map on an iPad and Garmin GLO GPS and GLONASS receiver, sites were easily and accurately located and navigated to in the field.

At each of the 5 sites, locations of which are shown in Figure 1, assessments of riparian and in-stream habitat (including periphyton and macrophyte) conditions and the macroinvertebrate and fish communities were conducted during base-flow conditions and following seven consecutive days of fine weather. All methods were in line with that detailed in the CCC Waterway Ecology Standard Sampling Methodology.

Habitat assessments and surveying of the macroinvertebrate and fish communities were conducted between 21 and 29 March 2016. At each site, habitat and macroinvertebrates were assessed within a 20 m reach. The fish community was then assessed within at least 30 m (minimum) including the habitat and macroinvertebrate reach on a subsequent day (either the following day or 5 days after the habitat assessment).

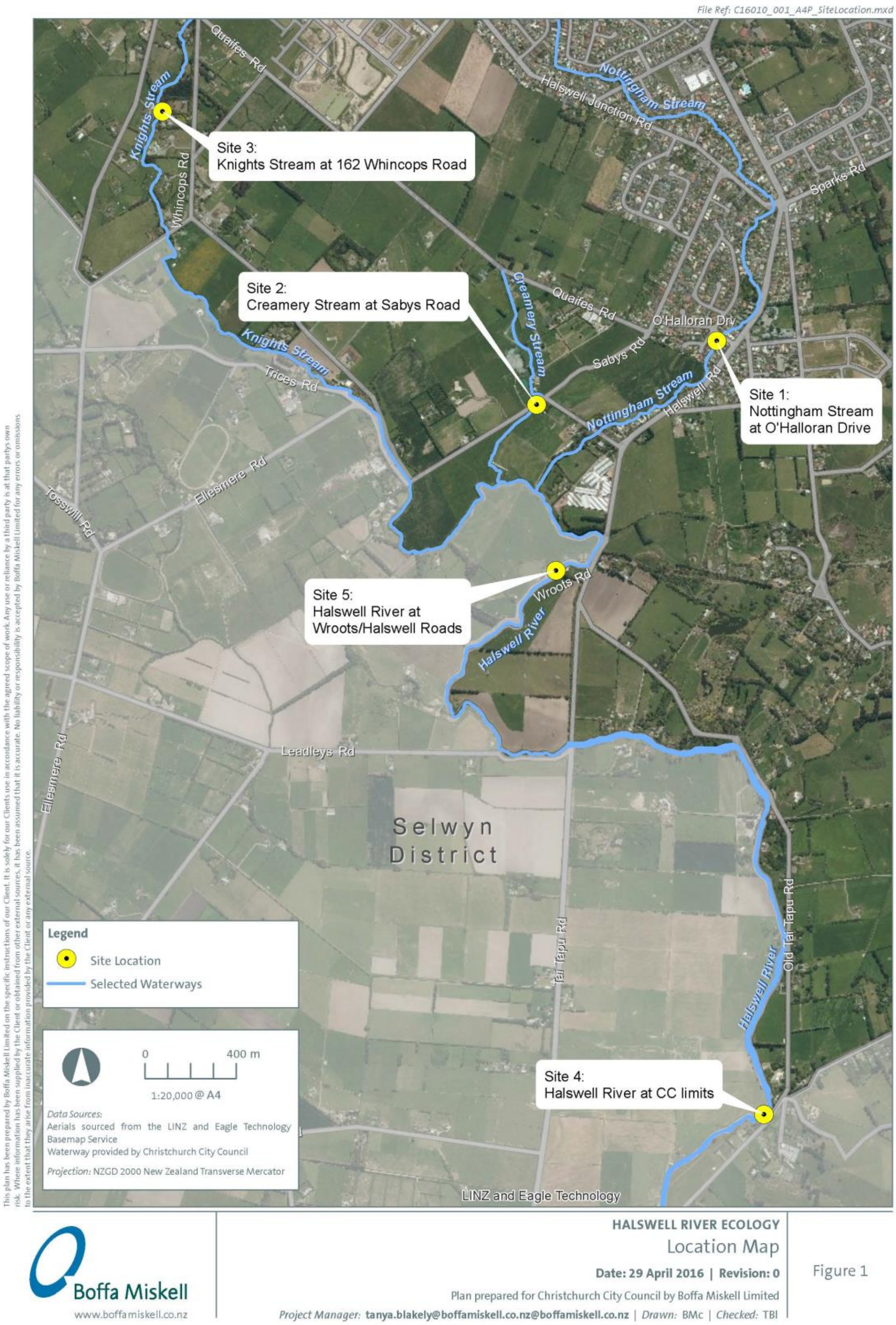

Figure 1. Locations of the five sites in the Halswell River catchment and within the South West Stormwater Management Plan area, surveyed in March 2016.

Habitat conditions

A variety of riparian and in-stream habitat parameters were recorded at each site, either at the site scale (i.e. one measure for the entire study site), or across three transects located within each site (i.e. multiple measures across transects). Photographs were also taken at each site.

Water quality

At each site, spot measures of specific conductivity, pH, dissolved oxygen, and water temperature were taken using a handheld Horiba multi-parameter water quality meter.

The percent composition of different flow habitats (i.e. riffle, run, or pool) was estimated for each site.

Three equally-spaced transects, spaced at 10 m intervals, were established across the waterway at each site, where the downstream most transect was approximately located at the co-ordinates provided in Table 1. Transects two and three were located 10 m and 20 m upstream of the first (transect one).

Water velocity was measured at each of the three transects, using a Seba Current Meter c/w counter and wading rods, where:

$$Velocity = (S * r.p.s) + C,$$

S = slope specific to the propeller used; *r.p.s* = revolutions per second as determined by the count meter; and *C* = constant.

Riparian and in-stream habitat

Total wetted width (m) was also recorded at each of the three transects, giving an average wetted width for each site. Canopy cover (%), bank erosion (%), extent of undercut bank (cm) and overhanging vegetation (cm) (if present), percent of bank with vegetation cover, bank slope (degrees), bank height (cm), type of bank material, types of riparian vegetation, and the surrounding land use were separately recorded on the true left and true right banks along each of these transects at each site.

Water depth (cm), soft sediment depth (cm), embeddedness (%), and substrate composition (%); depth (cm), percent cover, type (submerged or emergent), and dominant species of macrophytes present; percent cover and type of organic material (leaves, moss, coarse woody debris); and percent cover and type of periphyton were measured at five locations (TL bank, 25%, 50%, 75%, and TR bank) along each of the three transects at each site.

Embeddedness is a measure of the degree to which larger substrates are surrounded by fine particles, and therefore, an indication of the clogging of interstitial spaces.

Soft sediment depth was determined by gently pushing a metal wading rod (10 mm diameter) into the substrate until it hit the harder substrates underneath. Substrate composition was measured within an approximately 20 x 20 cm quadrat randomly placed at each of the five locations along the three transects. Within each quadrat, the percent composition of the following sized substrates was estimated: 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) (modified from Harding et al. 2009).

Sediment quality

Sediment samples were collected from multiple locations at each of the five survey sites, within the same reach as the habitat conditions and macroinvertebrate community was assessed. Surface sediment (approximately top 3 cm) was collected by scraping along the surface of the waterway bed with a sample container (prepared collection jar provided by Hills Laboratory) attached to a mighty gripper. Water was drained directly off the collected samples and transferred to a cooler bin before transporting to Hill Laboratories, an International Accreditation New Zealand (IANZ) laboratory.

Hill Laboratories conducted the following analyses (Table 2), all of which are IANZ accredited, except for total organic carbon (TOC) and the grain size analysis.

Table 2. Analyses conducted by Hill Laboratories on sediment samples collected from the five survey sites in March 2016.

Test	Method description	Reference
7 grain sizes profile	Wet sieving, gravimetric analysis	N/A
Total recoverable copper, lead, and zinc	Air dried at 35°C and sieved, <2 mm fraction. Nitric / hydrochloric acid digestion, ICP-MS, screen level.	US EPA 200.2
Total organic carbon (TOC)	Air dried at 35°C and sieved, <2 mm fraction. Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	N/A
Total recoverable phosphorus (TP)	Air dried at 35°C and sieved, <2 mm fraction. Nitric / hydrochloric acid digestion, ICP-MS, screen level.	US EPA 200.2
Polycyclic aromatic hydrocarbons (PAHs)	Air dried at 35°C and sieved, <2 mm fraction. Dried at 103°C for 4-22 hr, sonication extraction, SPE cleanup, GC-MS SIM analysis.	US EPA 3540, 3550 & 3630.
Semi-volatile organic compounds (SVOCs)	Air dried at 35°C and sieved, <2 mm fraction. Sonication extraction, SPE cleanup, GC-MS full scan analysis.	US EPA 3540, 3550, 3640 & 8270

Macroinvertebrate community

Macroinvertebrates (e.g., insects, snails and worms that live on the stream bed) can be extremely abundant in streams and are an important part of aquatic food webs and stream functioning. Macroinvertebrates vary widely in their tolerances to both physical and chemical conditions, and are therefore used regularly in biomonitoring, providing a long-term picture of the health of a waterway.

The macroinvertebrate community was assessed at each site within the same 20 m reach where riparian and in-stream habitat was surveyed. The macroinvertebrate community was sampled at each site on the same day that the habitat assessment was conducted (i.e. prior to habitat assessments, but after basic water chemistry and temperature parameters were measured).

A single and extensive composite kick-net (500 µm mesh) sample was collected from each site in accordance with protocols C1 and C2 of Stark et al. (2001). That is, each kick net sampled approximately 0.3 m x 2.0 m of stream bed, including sampling the variety of microhabitats present (e.g. stream margin, mid channel, undercut banks, macrophytes) so as to maximise the likelihood of collecting all macroinvertebrate taxa present at a site, including rare and habitat-specific taxa.

Macroinvertebrate samples were preserved, separately, in 70% ethanol prior to sending to Ryder Consulting, Dunedin, for identification and counting in accordance with protocol P3 (full count with subsampling option) of Stark et al (2001).

Fish community

The fish community was surveyed[2] within the same reach (minimum of 30 m in length) where the macroinvertebrate community and habitat assessments were made. However, the habitat and macroinvertebrate assessments were conducted between one and five days prior to the fish survey.

At sites 1, 2, and 3 (Nottingham, Creamery, and Knights Streams), the survey reach included the variety of habitats typically present in the reach being surveyed (e.g. stream margin, mid channel, undercut banks, macrophytes, silt, riffles, runs, pools). Survey reaches were divided into many subsections of approximately 2-3 m in length and electro-fished using a single pass with a Kainga EFM 300 backpack mounted electro-fishing machine (NIWA Instrument Systems, Christchurch). Fish were captured in a downstream push net or in a hand (dip) net and temporarily held in buckets. All fish were then identified, counted and measured (fork length, mm) before being returned alive to the stream. The electric fishing surveys were conducted on 29 March 2016.

Sites 4 and 5 (the two Halswell River sites) were too deep and, therefore, electric fishing techniques were not safe, nor an appropriate method for sampling. A combination of baited fyke nets and Gee minnow traps was used at these sites. At each site, two fyke nets (baited with tinned cat food), and five Gee minnow traps (baited with Marmite) were set within the 30 m survey reach late in the afternoon (23 March 2016) and left overnight. The following morning (24

[2] Boffa Miskell holds: a Special Permit to *take* fish issued by the Ministry for Primary Industries pursuant to Section 97(1) of the Fisheries Act 1996; and approvals from the Department of Conservation and North Canterbury branch of Fish and Game to use an electric fishing machine under regulation 51 of the Freshwater Fisheries Regulations 1983 and Section 26ZR of the Conservation Act 1987.

March 2016), all fish captured were identified and measured (fork length, mm) before being returned alive to the stream.

Data analyses

Riparian and in-stream habitat assessments

Where parameters were measured at five locations across each of the transects (i.e. water depth, sediment depth, embeddedness, and macrophyte and periphyton cover), these were averaged to give a mean value for each transect.

A substrate index (SI) was calculated from the five replicate substrate composition measures taken along each transect. These values were then averaged, to give a mean SI for each transect.

The SI was calculated using the formula (modified from Harding et al. 2009):

SI = (0.03 x %silt / sand) + (0.04 x %gravel) + (0.05 x %pebble) + (0.06 x (%small cobble + %large cobble)) + (0.07 x %boulder)

The calculated SI can range between 3 and 7, where an SI of 3 indicated 100% silt / sand and an SI of 7 indicated 100% boulders. That is, the larger the SI, the coarser the substrate and the better the habitat for macroinvertebrate and fish communities. Finer substrates generally provide poor, and often unstable, in-stream habitat, and smother food (algal) resources and macroinvertebrates inhabiting the waterway.

Wetted width was measured once at each of the three transects. These values were averaged to give a mean wetted width (m) for each site.

Changes in habitat over time

As part of the CCC’s long term monitoring of Christchurch’s waterways, EOS Ecology conducted a survey of the Halswell River catchment in March 2011, including sites of the SWSMP area (EOS Ecology 2011). This allowed a comparison to be made between some habitat conditions in 2011 (EOS Ecology 2011) and 2016 (this study).

For those parameters where field methods were comparable across the two surveys, analyses of variance (ANOVA) were used to test for differences over time (parameters tested included, water depth, sediment depth, velocity, and substrate index). Analyses were conducted on average values for each transect, giving three measures of each response variable for each site, in 2011 and 2015.

Response variables were log transformed to meet assumptions of normality and homogeneity of variances. ANOVAs were performed in R version 3.0.2 (The R Foundation for Statistical Computing 2013).

Sediment quality

Statistical comparisons between sites were not possible as only a single sample was collected from each site. Instead comparisons of the sediment analysis results are made to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).

Total PAHs were calculated by summing the 16 PAHs analysed, which are the PAHs listed as priority pollutants by the USEPA (1982). Total PAHs were normalised to 1% TOC, as recommended in ANZECC (2000), before comparison to the guidelines. Where one or more PAH compound was below the detection limit, half the detection limit was used in the calculation. This method is consistent with the approach used in many reports of sediment quality in Christchurch's waterways (e.g. NIWA 2015).

Sites were ranked from 1 (best) to 5 (worst) for sediment contaminant concentrations. These ranks were then summed to give an overall rank for each site, where 1 was the best site overall, and 5 was the worst site overall (based on sediment contaminant concentrations).

Changes in sediment quality over time

Qualitative comparisons were made between sediment contaminant concentrations found at similar locations to the five sites surveyed in this study (2016) with the findings from a previous survey conducted in 2005 by Kingett Mitchell (Kingett Mitchell Ltd 2005).

There were slight differences in the site locations between the two survey years, which needs to be considered when interpreting the results. Comparisons between sites were as per below:

- Site 1 (2016): HA2 & HA3 (2005)
- Site 2 (2016): HA6 (2005)
- Site 3 (2016): HA23 (2005)
- Site 4 (2016): HA26 & HA27 (2005)
- Site 5 (2016): HA25 (2005)

Macroinvertebrate community

Biotic indices and stream health metrics

The following macroinvertebrate metrics were calculated from each kick-net sample, to provide an indication of stream health:

- **Total abundance** – the total number of individuals collected in the composite kick-net sample collected at each site. Macroinvertebrate abundance can be a good indicator of stream health, or ecological condition, because abundance tends to increase in the presence of organic enrichment, particularly for pollution-tolerant taxa (e.g. chironomid midge larvae and oligochaete worms).
- **Taxonomic richness** – the total number of macroinvertebrate taxa recorded from the composite kick-net sample collected at each site. Streams supporting high numbers of taxa generally indicate healthy communities, however, the pollution sensitivity / tolerance of each taxon needs to also be considered.
- **EPT taxonomic richness** – the total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) from the composite kick-net sample collected at each site. These three insect orders (EPT) are generally sensitive to pollution and habitat degradation and therefore diversity of these insects provides a useful indicator of degradation. High EPT richness suggests high water quality, while low richness indicates low water or habitat quality.
- **EPT taxonomic richness (excl. hydroptilids)** – the total number of EPT taxa excluding the family Hydroptilidae. The algal piercing caddisflies belonging to the family

Hydroptilidae are generally considered more tolerant of degraded conditions than other EPT taxa. Excluding hydroptilid caddis from the EPT metric is a more conservative approach and more accurately represents the 'clean-water' EPT taxa.

- **%EPT richness** – the total abundance of macroinvertebrates that belong to the pollution-sensitive EPT orders, relative to the total abundance of all macroinvertebrates found in the composite kick-net collected at each site. High %EPT richness suggests high water quality.
- **%EPT richness (excl. hydroptilids)** – the percentage abundance of EPT taxa at each transect, excluding the more pollution-tolerant hydroptilid caddisflies.
- **Macroinvertebrate Community Index (MCI)** – this index is based on tolerance scores for individual macroinvertebrate taxa found in hard- or soft-bottomed streams (Stark 1985, Stark and Maxted 2007). These tolerance scores, which indicate a taxon's sensitivity to in-stream environmental conditions, are summed for the taxa present in a sample, and multiplied by 20 to give MCI values ranging from 0 – 200. Table 3 provides a summary of how MCI scores were used to evaluate stream health.
- **Quantitative Macroinvertebrate Community Index (QMCI)** – this is a variant of the MCI, which instead uses abundance data. The QMCI provides information about the dominance of pollution-sensitive species in hard- or soft-bottomed streams. Table 3 provides a summary of how QMCI scores were used to evaluate stream health.

Table 3. Interpretation of MCI and QMCI scores for hard- and soft-bottomed streams (Stark & Maxted 2007).

Stream health	Water quality descriptions	MCI	QMCI
Excellent	Clean water	>119	>5.99
Good	Doubtful quality or possible mild enrichment	100-119	5.00-5.90
Fair	Probable moderate enrichment	80-99	4.00-4.99
Poor	Probable severe enrichment	<80	<4.00

Note, the MCI and QMCI (hard- and soft-bottom scores) were developed primarily to assess the health of streams impacted by agricultural activities (e.g. organic enrichment) and should be interpreted with caution in relation to urban systems.

Sites were ranked from 1 (best) to 5 (worst) for the following biotic indices: taxonomic richness, EPT richness, %EPT richness, and QMCI scores. Other biotic indices were not included as many are derivatives of these key indices. These ranks (of the included biotic indices) were then summed to give an overall rank for each site, where 1 was the best site overall, and 5 was the worst site overall (based on the four biotic indices).

Changes in macroinvertebrate community over time

Visual comparisons were made between taxonomic richness, EPT richness, and QMCI values calculated for 2011 (EOS Ecology 2011) and 2016 (this study); statistical analyses were not conducted as there was no replication within sites.

A non-metric multidimensional scaling (or NMDS) ordination[3], with 1000 random permutations, of abundance data was used to determine if the macroinvertebrate community found was similar between 2011 (EOS Ecology 2011) and 2016 (this study).

NMDS ordinations rank sites such that distance in ordination space represents community dissimilarity (in this case using the Bray-Curtis metric). Therefore, an ordination score (an *x* and a *y* value) for the entire macroinvertebrate community found at a 'site' can be presented on an *x*-*y* scatterplot to graphically show how similar (or dissimilar) the community was between 2011 and 2016. Ordination scores that are closest together are more similar in macroinvertebrate community composition, than those further apart (Quinn and Keough 2002).

An analysis of similarities (ANOSIM), with 100 permutations, was then used to test for significant differences in macroinvertebrate community composition between 2011 and 2016. It is helpful to view ANOSIM results when interpreting an NMDS ordination. An NMDS ordination may show that communities appear to be quite distinct (i.e. when shown graphically, sites could be quite distinct from one another in ordination space), but ANOSIM results show whether these differences are in fact statistically significantly different[4].

If ANOSIM revealed significant differences in macroinvertebrate community composition (i.e. $R \neq 0$ and $P \leq 0.05$) between years, similarity percentages (SIMPER) were calculated[5] to show which macroinvertebrate taxa were driving these differences.

NMDS, ANOSIM and SIMPER analyses were performed in PRIMER version 6.1.13 (Clarke and Warwick 2001).

Fish community

In order to account for the inevitable differences in areas sampled at each site, fish catches were converted into catch per unit effort (CPUE). Electric fishing data were converted to number of fish captured per 100 m^2 of stream surveyed; trapping data were presented as number of fish captured per trap, per night.

Changes in fish community over time

Qualitative comparisons were made between the fish community found at 4 sites in this study (2016) with the findings from previous surveys conducted in 2011 by Aquatic Ecology Ltd (Aquatic Ecology Ltd 2012) and in 2004 by Kingett Mitchell Ltd, Aquatic Ecology Ltd, and EOS Ecology Ltd (CCC 2005). Note, survey locations are not entirely overlapping, and the comparisons in fish fauna overtime are from approximately similar site locations.

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[3] Goodness-of-fit of the NMDS ordination was assessed by the magnitude of the associated 'stress' value. A stress value of 0 indicates perfect fit (i.e. the configuration of points on the ordination diagram is a good representation of actual community dissimilarities). It is acceptable to have a stress value of up to 0.2, indicating an ordination with a stress value of <0.2 corresponds to a good ordination with no real prospect of misleading interpretation (Quinn & Keough 2002).

[4] ANOSIM is a non-parametric permutation procedure applied to the rank similarity matrix underlying the NMDS ordination and compares the degree of separation among and within groups (i.e. sites or years) using the test statistic, R. When R equals 0 there is no distinguishable difference in community composition, whereas an R-value of 1 indicates completely distinct communities (Quinn & Keough 2002). A negative R indicates dissimilarities within groups are greater than dissimilarities between groups.

[5] The SIMPER routine computes the percentage contribution of each macroinvertebrate taxon to the dissimilarities between all pairs of sites among groups.

Results

Habitat conditions

Water quality

Specific conductivity

Conductivity, which is often used to indicate the level of pollutants in the water column, was relatively similar across the five sites, ranging between 217 µS / cm and 286 µS / cm (Figure 2). The highest recorded conductivity was in Site 2: Creamery Stream. However, the difference between the conductivity recorded in Creamery Stream and that of other sites was negligible. Moreover, the conductivities were similar to those recorded in many urban systems, and were generally similar to those recorded in the Heathcote River and Avon River catchments in 2013 and 2015, respectively (Boffa Miskell 2014; 2015).

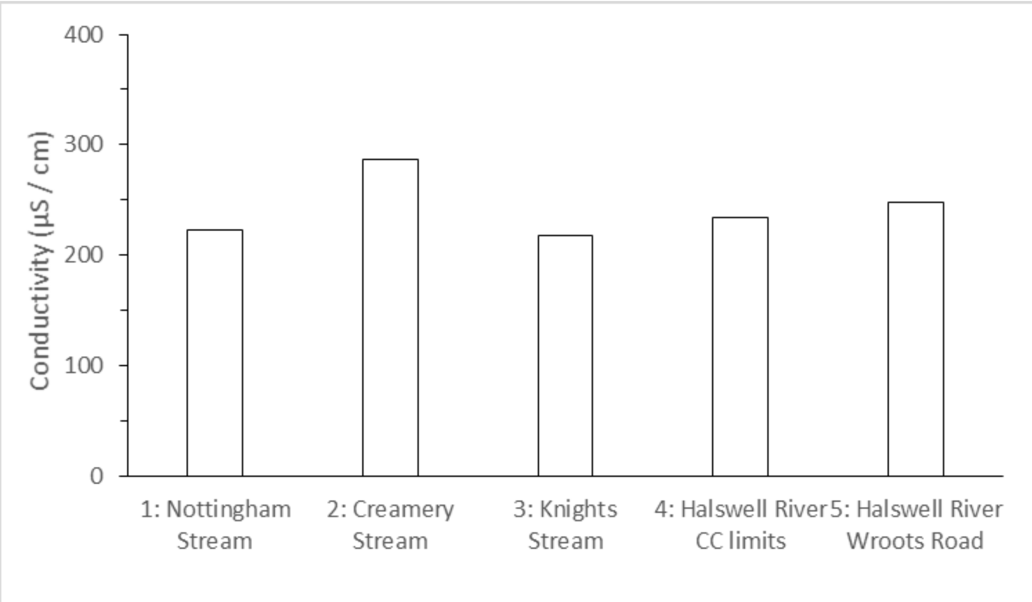

Figure 2. Specific conductivity measured, on one occasion, at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

pH

pH was similar across sites, with circum-neutral pH recorded in all five sites surveyed (Figure 3). These spot measures (i.e. a single measurement on one occasion) of pH also met Environment Canterbury's Land and Water Regional Plan (LWRP) water quality standard for receiving waters of pH between 6.5 and 8.5. However, it's important to note that pH can fluctuate both daily and seasonally.

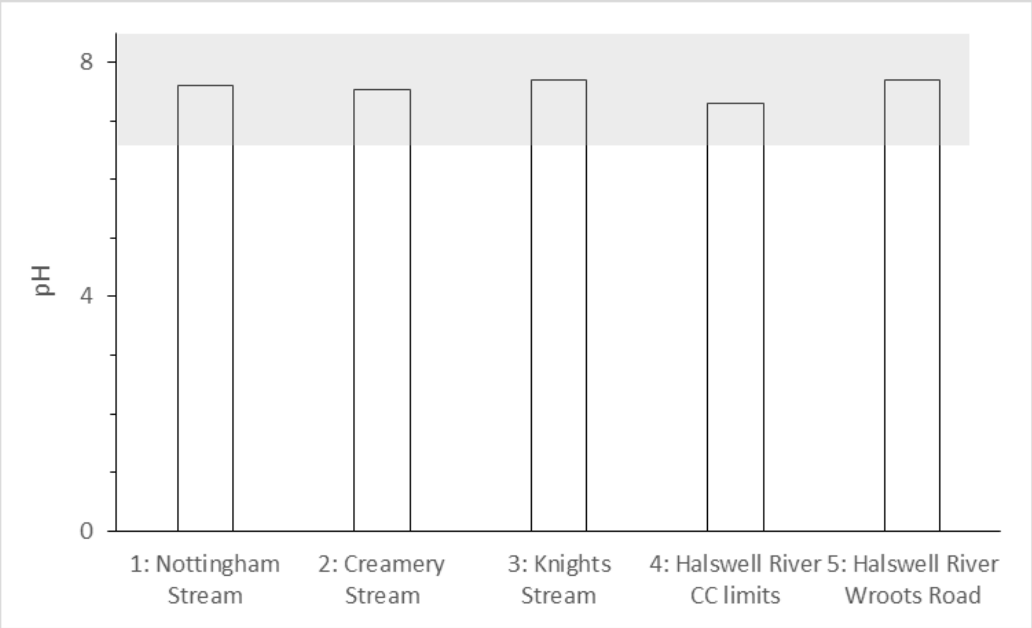

Figure 3. pH measured, on one occasion, at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016. The grey shaded area indicates Canterbury's Land and Water Regional Plan (LWRP) recommended water quality standard for receiving waters of pH between 6.5 and 8.5.

Dissolved oxygen

Dissolved oxygen (DO) was variable across sites, with particularly low DO recorded in Site 1: Nottingham Stream and Site 3: Knights Stream (Figure 4). It is important to note that both of these waterways had very low water levels at the time of sampling. Moreover, DO was measured only once during the daytime, and at different times of the day across the five sites. DO can vary diurnally and seasonally.

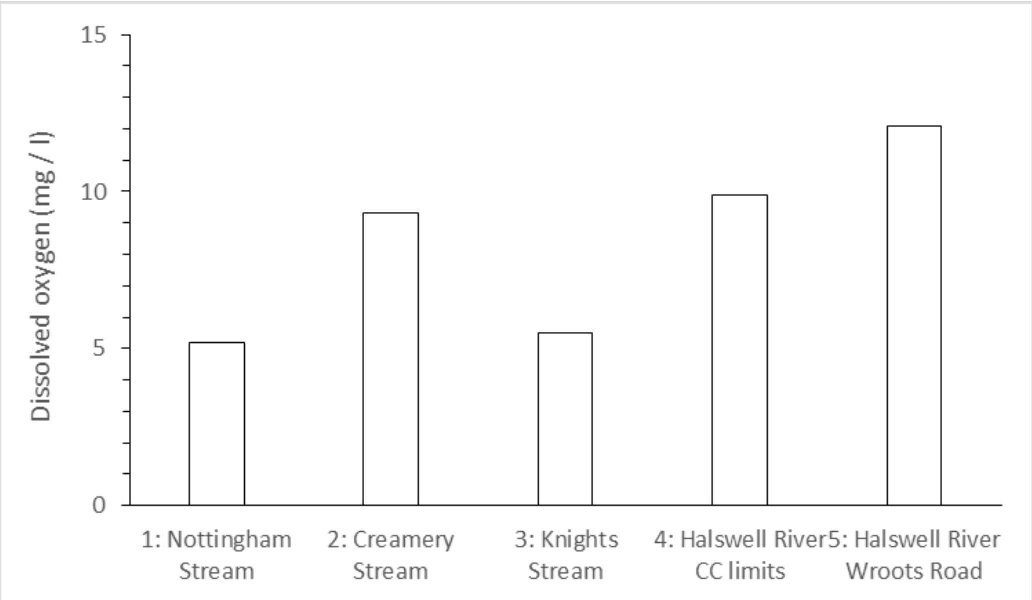

Figure 4. Dissolved oxygen (DO) measured, on one occasion, at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Water temperature

Water temperature was variable across sites, but generally low (i.e. cool) with temperatures at all sites below the LWRP guideline of 20°C for Canterbury Rivers (Figure 5). The coolest water temperature of 13.7°C was recorded in Site 3: Knights Stream, while Site 5: Halswell River at Wroots Road had the highest water temperature (18.1°C). Water temperatures recorded in the 5 sites surveyed in this study were generally similar to those recorded in the Heathcote River and Avon River catchments in 2013 and 2015, respectively (Boffa Miskell 2014; 2015). It is important to note, however, that temperature was measured only once during the daytime, and at different times of the day across the five sites; water temperature can vary diurnally and seasonally.

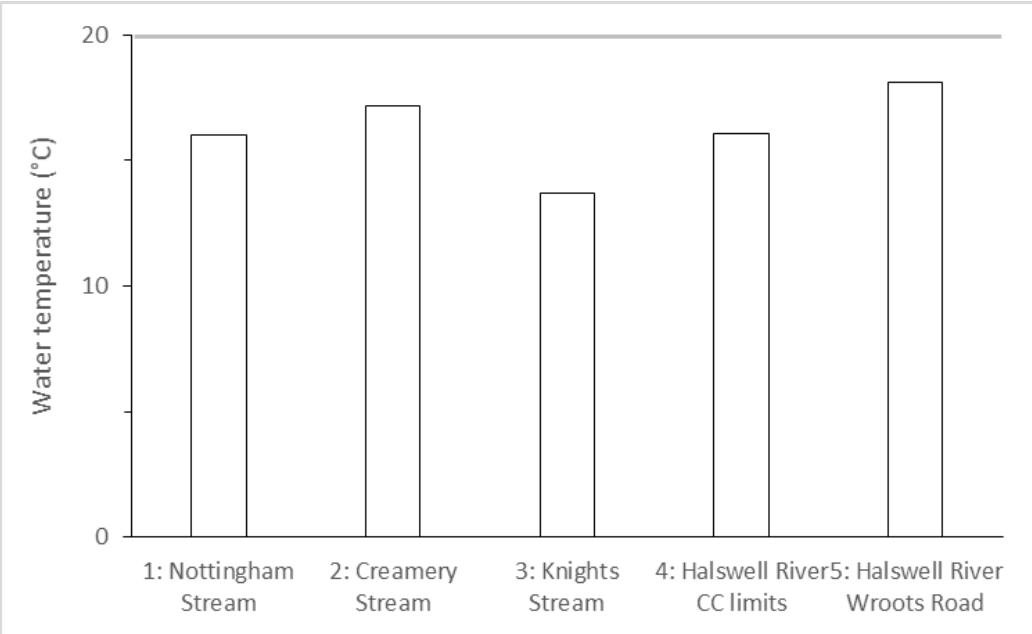

Figure 5. Water temperature measured, on one occasion, at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Velocity

Water velocity was highly variable amongst sites, with the fastest velocity recorded in Site 2: Creamery Stream, while Site 3: Knights Stream and Site 1: Nottingham Stream had the slowest velocities (Figure 6). Velocity at the two Halswell River sites (Sites 4 and 5) were relatively similar.

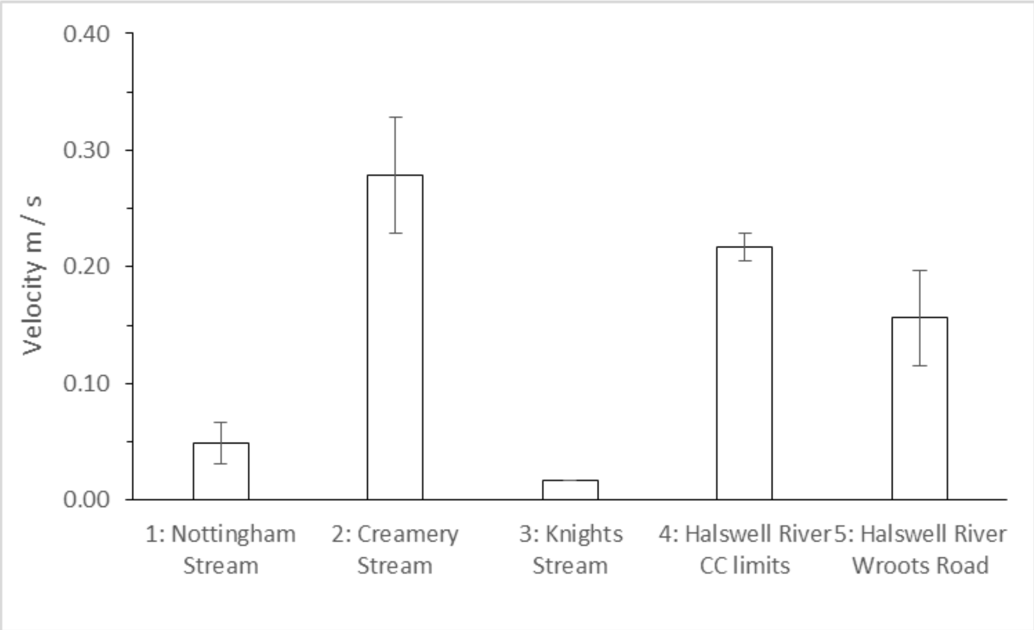

Figure 6. Mean (±1SE, n = 3) velocity (m / s) measured once at each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Velocity was significantly different among sites (ANOVA: $F_{4, 20} = 20.37$; $P < 0.001$), and different between years (ANOVA: $F_{1, 20} = 11.07$; $P = 0.003$) (Figure 7). Velocity was generally slower in 2016, than in 2011, with the exception of Site 2: Creamery Stream, where it was greater (although not significant) in 2016 (Boffa Miskell, this study), than in 2011 (EOS Ecology 2011).

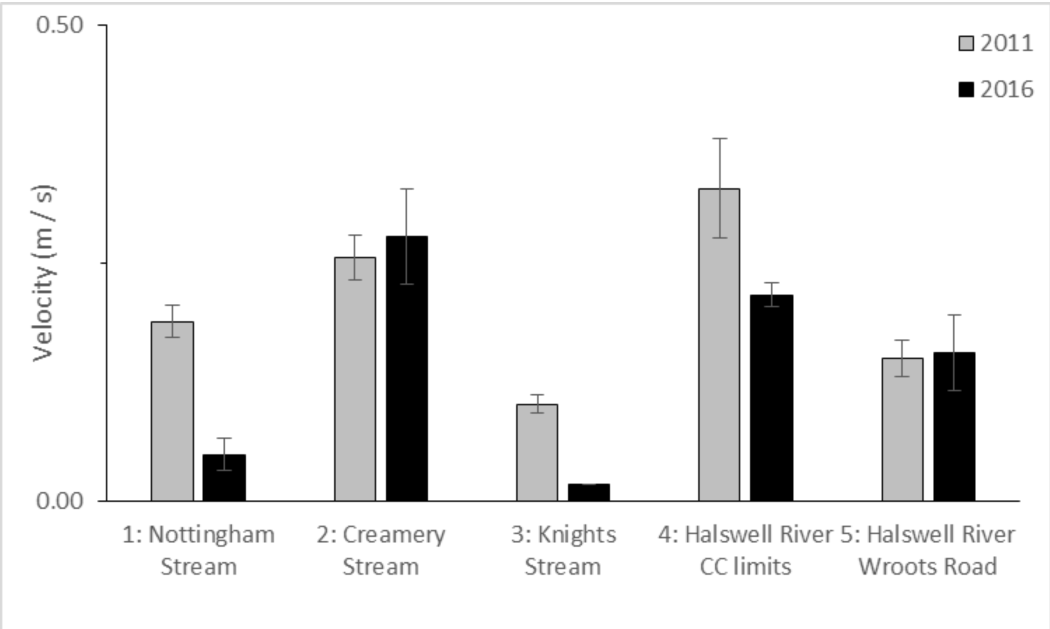

Figure 7. Mean (±1SE, n = 3) velocity (m / s) measured once at each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2011 (grey bars; EOS Ecology 2011) and March 2015 (black bars; this study).

Riparian and in-stream habitat

A brief summary of the general habitat conditions encountered at each site is given in Table 4; further site descriptions are provided below.

Table 4. Summary of the riparian and in-stream habitat conditions at each of the five sites surveyed between 21 and 23 March 2016. TLB = true left bank; TRB = true right bank.

	Surrounding land use	**Bank material**	**Canopy cover**	**Horizontal bank undercut**	**Overhanging vegetation**	**Ground cover vegetation (%)**	**Flow habitat type (%still: backwater: pool: run: riffle)**
Site 1: Nottingham Stream at O'Halloran Drive	TLB: Residential TRB: Residential	TLB: timber TRB: timber	TLB: 37% TRB: 12%	TLB: 0 cm TRB: 7 cm	TLB: 13 cm TRB: 8 cm	TLB: 5% TRB: 7%	15:0:0:85:0
Site 2: Creamery Stream at Sabys Road	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth and rock	TLB: 65% TRB: 47%	TLB: 23 cm TRB: 10 cm	TLB: 0 cm TRB: 3 cm	TLB: 17% TRB: 27%	0:0:0:100:0
Site 3: Knights Stream at 162 Whincops Road	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth	TLB: 17% TRB: 53%	TLB: 0 cm TRB: 3 cm	TLB: 0 cm TRB: 10 cm	TLB: 70% TRB: 57%	95:0:0:5:0
Site 4: Halswell River at Christchurch City limits	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 3 cm TRB: 0 cm	TLB: 20 cm TRB: 33 cm	TLB: 67% TRB: 34%	0:0:0:100:0
Site 5: Halswell River at Wroots / Halswell Roads	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 17 cm TRB: 0 cm	TLB: 3 cm TRB: 0 cm	TLB: 100% TRB: 100%	0:0:0:100:0

General site descriptions

Site 1: Nottingham Stream at O'Halloran Drive

This site was located in Nottingham Stream approximately 1 km upstream of its confluence with the Halswell River. Here the stream was approximately 1.65 m wide and very shallow, with an average water depth of 3.5 cm. The velocity on the day of sampling was 0.05 m / s. The wetted width and water depth was thought to be unusually low due to unseasonably dry weather over the preceding summer months. Much of the stream channel was lined with timber, constraining its path. However, this did allow for slightly deeper water along the sides of the channel, which supported a large bully population.

The stream bed was dominated by pebbles and gravels, with an average Substrate index of 4.5. However, these coarser substrates were highly embedded by fine substrates. Macrophytes were very uncommon within the site, while thin algal cover was relatively abundant (due to the abundance of coarse substrates). This site had the most abundant cover of long filamentous algae, however, this was still below the LWRP guideline of 30%.

Due to the timber lined channel and very low water levels, in-stream habitat was limited to deeper water along the sides of the channel. Gaps between the horizontal posts of the timber lined walls provided some habitat for freshwater fishes, including upland bullies.

Photo 1. Site 1: Nottingham Stream, approximately 1 km upstream of its confluence with the Halswell River, looking upstream (top left) and downstream (top right), looking downstream from top of survey site (bottom).

Site 2: Creamery Stream at Sabys Road

Site 2 was located on Creamery Stream, downstream of the Sabys Road culvert, and approximately 400 m upstream of its confluence with Knights Stream, the headwater tributary of the Halswell River. The site was 100% run habitat, but there was a swift, deep section immediately downstream of the culvert and just upstream of the survey site. Here the stream was approximately 1.6 m wide, with an average water depth of 34 cm. The velocity on the day of sampling was 0.28 m / s. Although the stream channel was natural earth (rather than lined), it was very straight and had the appearance of being regularly maintained for drainage.

The high canopy cover at this site afforded a great deal of shading to the stream, and macrophyte and algal growth was minimal. There was a paucity of in-stream habitat availability, with a substrate index of 3, and a high and relatively thick cover of fine / soft sediment.

Photo 2. Site 2: Creamery Stream downstream of Sabys Road, approximately 400 m upstream of its confluence with the Halswell River, looking upstream (left) and downstream (right).

The downstream end of the culvert was perched and may present a barrier to fish passage.

Photo 3. Downstream end of road culvert (Sabys Road) immediately upstream of Site 2: Creamery Stream. The culvert was perched and may present as a barrier to fish passage.

Site 3: Knights Stream at 162 Whincops Road

Site 3: Knights Stream was located along Whincops Road, downstream of Quaifes Road, and approximately 3.5 km upstream of where it joins the Halswell River.

Knights Stream at Site 3 was approximately 1 m wide with around 5 cm water depth. The site was located at and downstream of the spring head; the channel was dry immediately upstream of the site. At the time of sampling there was virtually no flow and velocity was unable to be measured. The sides of the stream channel were earth, with an array of native shrubs and trees providing substantial shade to the stream in places.

The stream bed was dominated by organic material, and soft fine sediments, as indicated by the low substrate index of 3. Macrophytes and algae were uncommon, but willow roots protruded into the channel providing some stable undercut banks.

Water levels were very low along much of the site (only a few centimetres), but a deep pool was present at the spring head. This is where the majority of the fish, especially eels, were encountered.

Photo 4. Site 3: Knights Stream downstream at Whincops Road, approximately 3.5 km upstream of its confluence with the Halswell River, above the site looking upstream (top), looking downstream (middle), and looking upstream to at the pool / spring head.

Site 4: Halswell River at Christchurch City limits

This site was located in the Halswell River at the edge of the Christchurch City Councils territory, at the boundary with Selwyn District Council territory. The Halswell River at Site 4 was approximately 4 m wide with deep (44 cm) water. The velocity on the day of sampling was 0.22 m / s. The river bed was almost entirely covered with a deep layer of soft, fine (almost clay-like) sediment (substrate index of 3.2). Macrophyte beds were virtually absent from much of the site, and algal cover was not obvious. It appeared as if the macrophyte beds had recently been mechanically removed from the river, however, Environment Canterbury confirmed that macrophytes had not been cleared from this site since June 2015.

The river banks were unlined (earth) with weeds growing to the water's edge on the true left bank, and rank grass with willow and other introduced trees on the true right bank. Where macrophytes were present, they were dominated by the exotic species *Potamogeton crispus* and *Elodea canadensis*.

Photo 5. Site 4: Halswell River at the CC limits, looking upstream (left) and downstream (right).

Site 5: Halswell River at Wroots / Halswell Roads

Site 5 was also located on the Halswell River but approximately 4 km upstream of site 4 and 700 m downstream of where Knights Stream and the Halswell River converge. Here the site was approximately 6 m wide and around 50 cm deep. The bed was again dominated by a deep layer of soft, fine sediment, with a lack of coarser substrates (reflected by the substrate index of 3). Macrophyte cover was high at this site with approximately 50% cover at the site, dominated by the exotic species *Elodea canadensis*, *Potamogeton crispus*, and *Nasturtium officinale*.

The river banks here were also unlined, with grass and weeds (e.g. convolvulus) growing down to the water's edge. Scattered flaxes (*Phormium*) were present along the true right bank. There was evidence of some lateral spreading along the true right banks, indicated by large crevices and cracks (overgrown by grasses) parallel to the road and river.

Photo 6. Site 5: Halswell River at Wroots / Halswell Road, looking downstream (left) and upstream (right).

Wetted width and water depth

Wetted width was greatest in the two Halswell River sites (Sites 4 and 5) and narrowest in the three tributary waterways (Nottingham Stream, Creamery Stream, and Knights Stream) (Figure 8).

Water depth showed a similar pattern with the greatest depths recorded in the two Halswell River sites (Sites 4 and 5) and the shallowest depths recorded in Site 3: Knights Stream and Site 1: Nottingham Stream. Site 2: Creamery Stream was relatively similar in depth to the Halswell River sites (Figure 8).

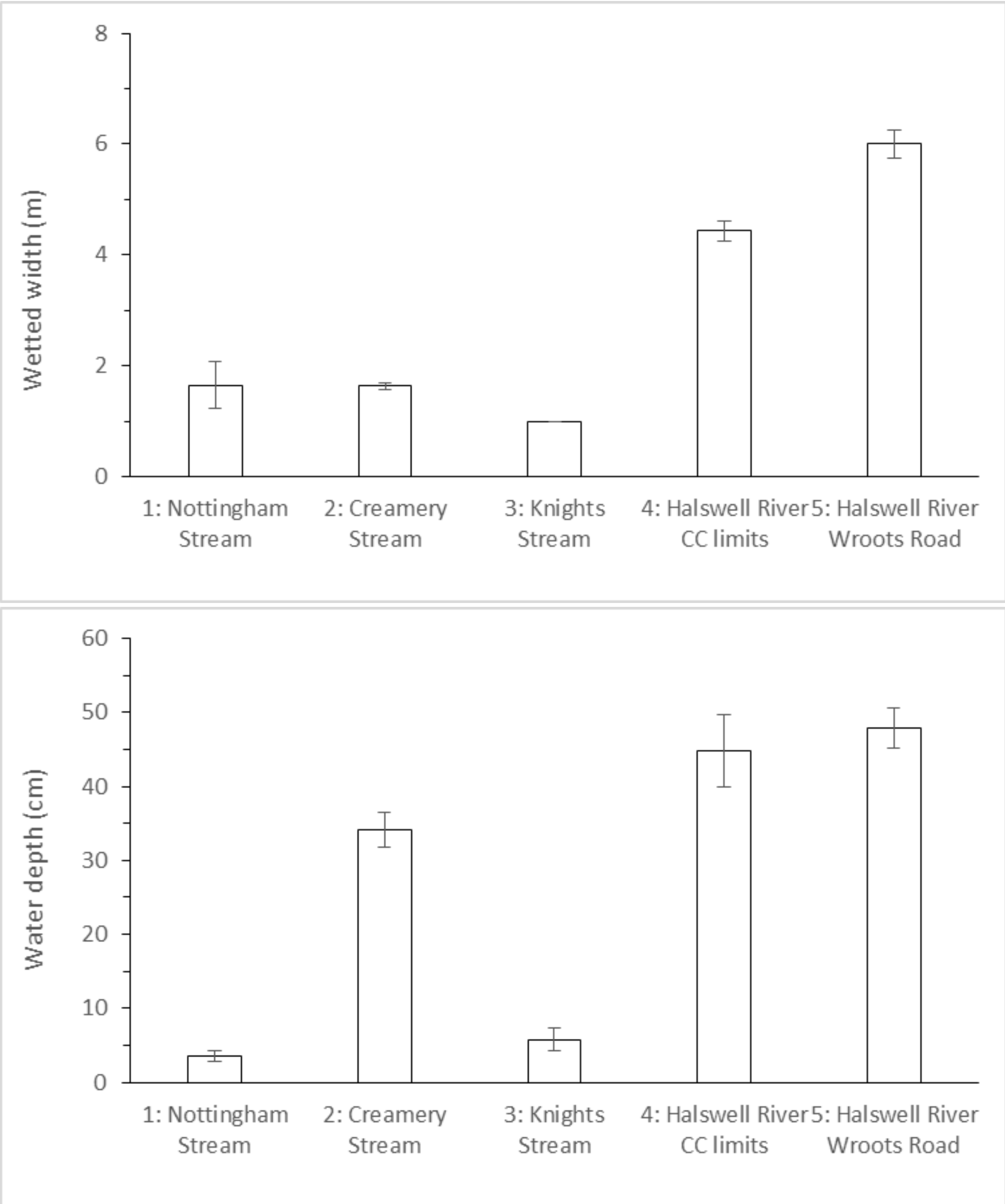

Figure 8. Mean (±1SE, n = 3) wetted width (m) (top) and water depth (cm) (bottom) measured once at each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Water depth was significantly different among sites (ANOVA: $F_{4, 20} = 24.46$; $P < 0.001$), and different between years (ANOVA: $F_{1, 20} = 4.88$; $P = 0.039$) (Figure 9). Water depth was generally deeper in 2016, than in 2011, with the exception of Site 1: Nottingham Stream and Site 3: Knights Stream, which had significantly shallower water depths recorded by Boffa Miskell in 2016, than by EOS Ecology in 2011. The 2016 survey was conducted after a markedly dry summer, with very little rain falling in Christchurch.

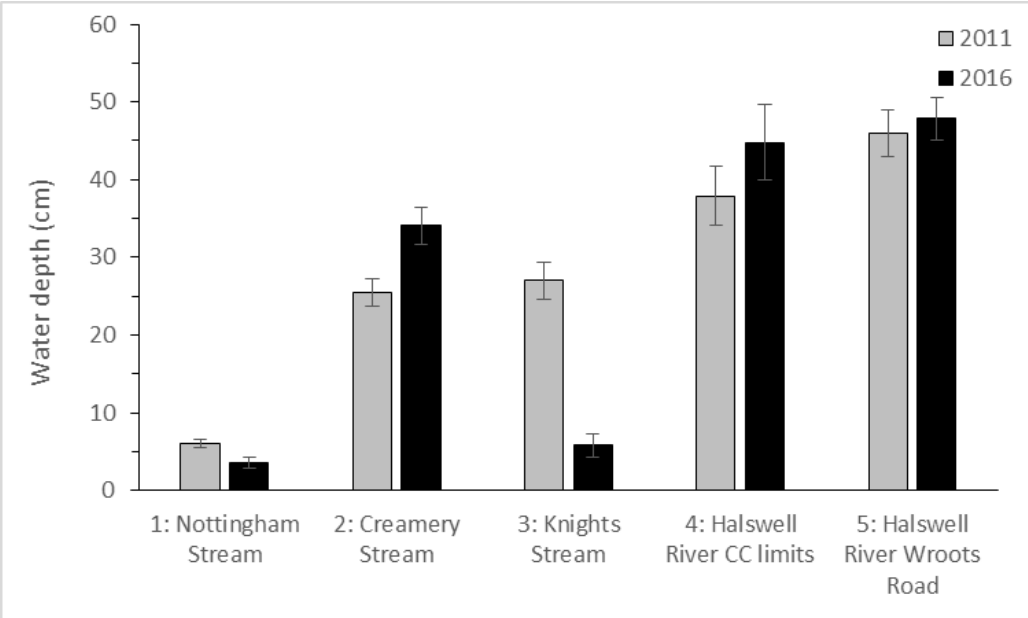

Figure 9. Mean (±1SE, n = 3) water depth (cm) measured once at each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2011 (grey bars; EOS Ecology 2011) and March 2015 (black bars; this study).

Substrate index

The substrate index (SI), calculated from five replicate measures of substrate composition taken along each of the three transects at each site, generally ranged between 3.0 and 4.5. Site 1: Nottingham Stream had the greatest SI of 4.5, indicating coarser substrates dominated by pebble and gravels, than the silt/sand dominated beds of all other sites (Figure 10).

Fine sediments (<2 mm diameter) were estimated to cover approximately 50% of the stream bed in Nottingham Stream (Site 1), and between 90% and 100% in Site 2: Creamery Stream, Site 3: Knights Stream and both Halswell River sites (Sites 4 and 5). Fine sediment percent cover at all five sites exceeded that of the SWSMP consent surface water quality objectives of 40% (maximum) cover. This high cover of fine sediment at all sites surveyed was also reflected in the estimated embeddedness scores, as discussed below.

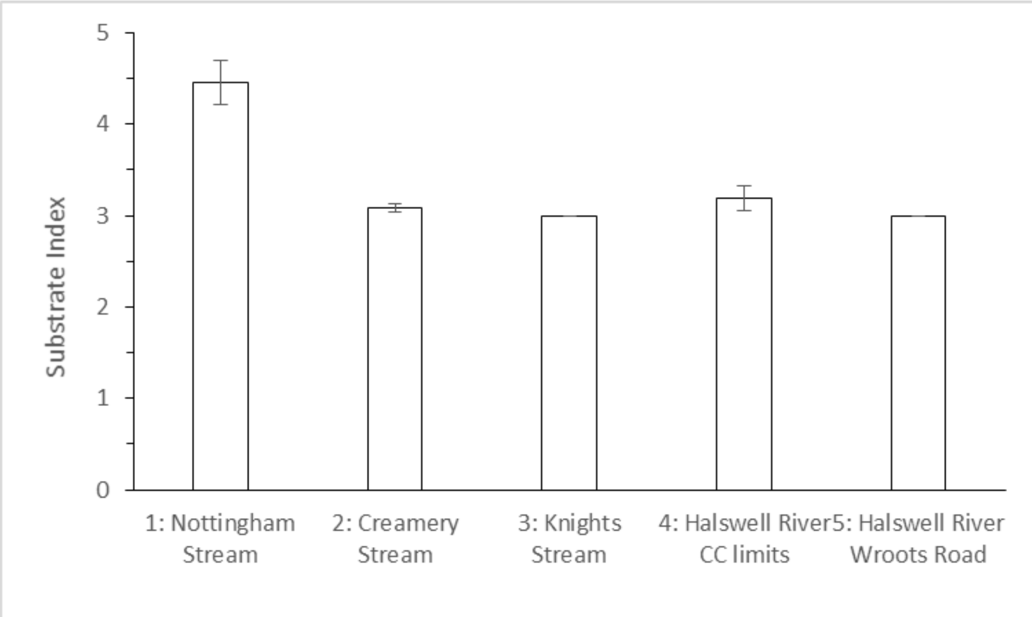

Figure 10. Mean (±1SE) substrate index calculated from substrate composition measures recorded at five locations along each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Substrate Indexes were different among sites (ANOVA: $F_{4, 20} = 49.89$; $P < 0.001$), and different between years (ANOVA: $F_{1, 20} = 206.83$; $P < 0.001$) (Figure 11). All sites were estimated to have coarser substrate in 2016, than that measured by EOS Ecology in 2011. However, the method to estimate Substrate Index was slightly different between 2011 and 2016[6]. Nevertheless, in general, Site 1: Nottingham Stream had the greatest SI, indicating coarser substrates dominated by pebble and gravels, than the silt/sand dominated beds of all other sites (Figure 11).

[6] The Substrate Index was calculated using slightly different methods in 2011 versus 2016. EOS Ecology (2011) categorised each of 12 randomly selected particles collected at each transect, each of which was assigned a Substrate Index *value*. The 12 Substrate Index *values* (where "silt" was scored as "0.10", "sand" scored "0.20", "gravel" scored "0.30", and so on) estimated at each transect were summed to give a Substrate Index *score* for each transect. The three Substrate Indexes were averaged to give a Substrate Index *score* per site. Boffa Miskell (2016) estimated substrate composition (%) at each transect, and the percent values for each substrate category were used to calculate a Substrate Index *score* for each transect, as described in the methodology section of this report.

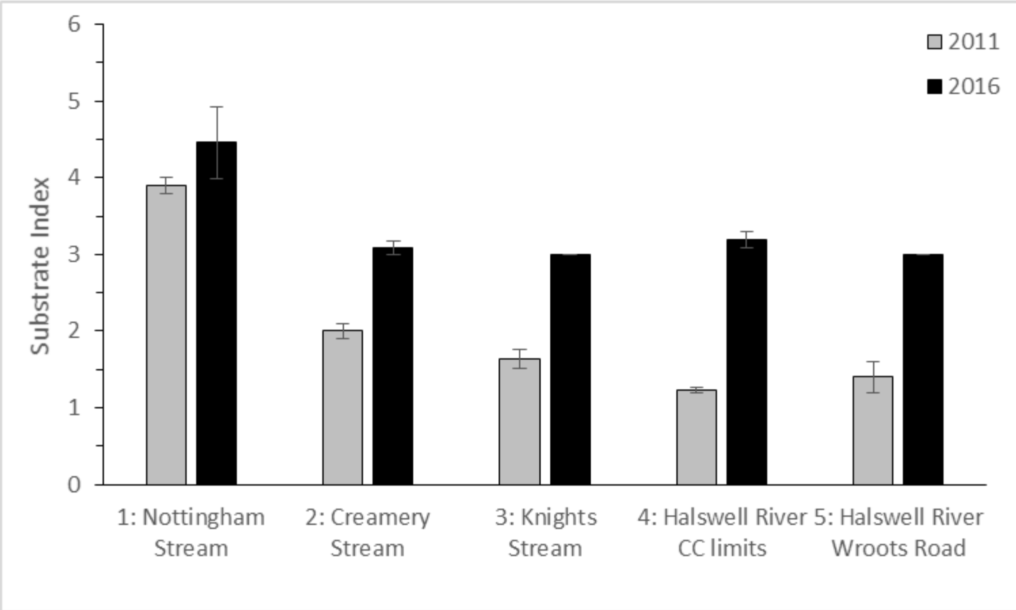

Figure 11. Mean (±1SE, n = 3) Substrate Index measured once at each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2011 (grey bars; EOS Ecology 2011) and March 2015 (black bars; this study).

Embeddedness

Percent embeddedness, a measure of the degree to which coarse substrates (e.g. gravel and cobbles) are surround and buried by fine substrates (e.g. silt and sand), was high across all sites with 100% embeddedness recorded in Site 1: Creamery Stream, Site 3: Knights Stream, and the two Halswell River sites. Embeddedness was estimated to be slightly lower in Site 1: Nottingham Stream, compared to the other sites surveyed (Figure 12). Sites with the lowest SIs also had the highest embeddedness scores, which is unsurprising given that a low SI indicates bed substrates dominated by fine particles, which are also the particles that embed (surround) coarser substrates.

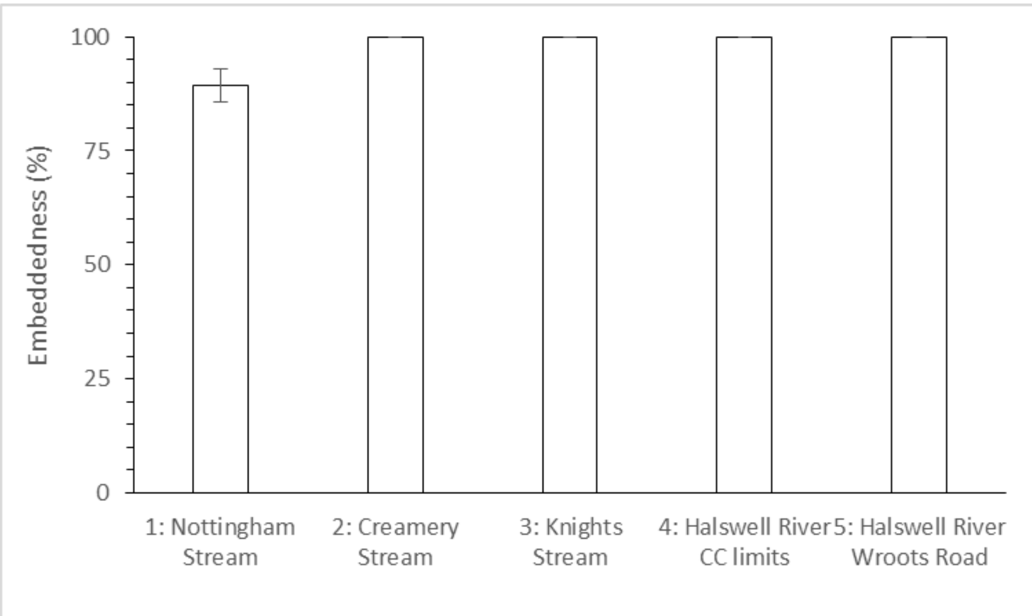

Figure 12. Mean (±1SE) percent embeddedness recorded at five locations along each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Soft sediment depth

Soft sediment depth was greatest in Site 5: Halswell River at Wroots Road, Site 2: Creamery Stream, and Site 4: Halswell River at the Christchurch City limits (Figure 13). On average, the two Halswell River sites (Sites 4 and 5) and Site 2: Creamery Stream had between 100 and 150 cm of soft / fine sediment covering the stream bed.

Although all sites had a very high percent of fine sediment covering the stream bed, and generally high embeddedness scores, Site 1: Nottingham Stream and Site 3: Knights Stream had comparatively shallow soft sediment deposits.

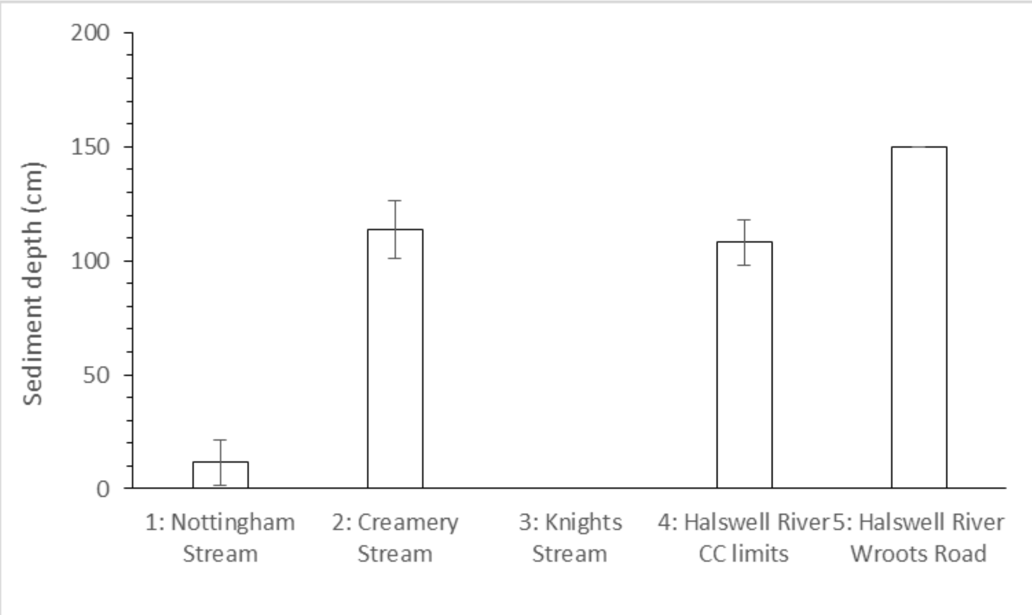

Figure 13. Mean (±1SE) soft sediment depth recorded at five locations along each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

Soft sediment depth was significantly different across the sites (ANOVA: $F_{4, 20} = 56.42$; $P < 0.001$), and different between years (ANOVA: $F_{1, 20} = 16.37$; $P < 0.001$) (Figure 14). More sediment was recorded in all sites, except Site 3: Knights Stream, in 2016 (this study) than in 2011 (EOS Ecology 2011).

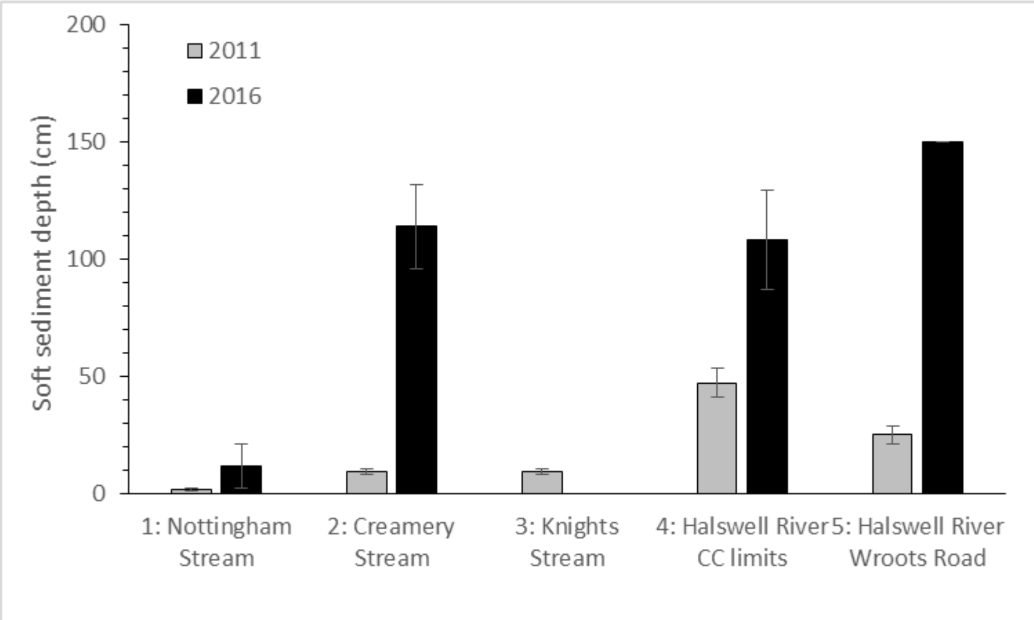

Figure 14. Mean (±1SE, n = 3) depth of soft sediment covering the stream bed, measured once at each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2011 (grey bars; EOS Ecology 2011) and March 2015 (black bars; this study).

Macrophytes

The percentage that macrophytes cover the stream bed was relatively low across all sites, except total macrophyte cover in Site 5: Halswell River at Wroots Road (Figure 15). Macrophytes were generally absent from Site 1: Nottingham and Site 3: Knights Streams, presumably due to the extensive canopy cover over both survey sites. Site 2: Creamery Stream had a similarly low cover of macrophytes. Site 4: Halswell River at the CC limits appeared to have been dredged or cleared of macrophytes recently, however, Mike Hyett of Environment Canterbury confirmed that both Halswell River sites (Sites 4 and 5) were last cleared (of macrophytes) in June 2015.

Total macrophyte cover at Site 5: Halswell River at Wroots Road exceeded the 50% (maximum) guideline of total macrophyte cover recommended in the the SWSMP consent surface water quality objectives. All other sites surveyed were below both the SWSMP guidelines for total macrophyte cover; all sites were below the LWRP guidelines for emergent macrophyte cover (30% maximum cover) (Figure 15).

Macrophytes at all five sites surveyed were dominated by the commonly occurring exotic species, curly pondweed (*Potamogeton crispus*) and Canadian pondweed (*Elodea canadensis*).

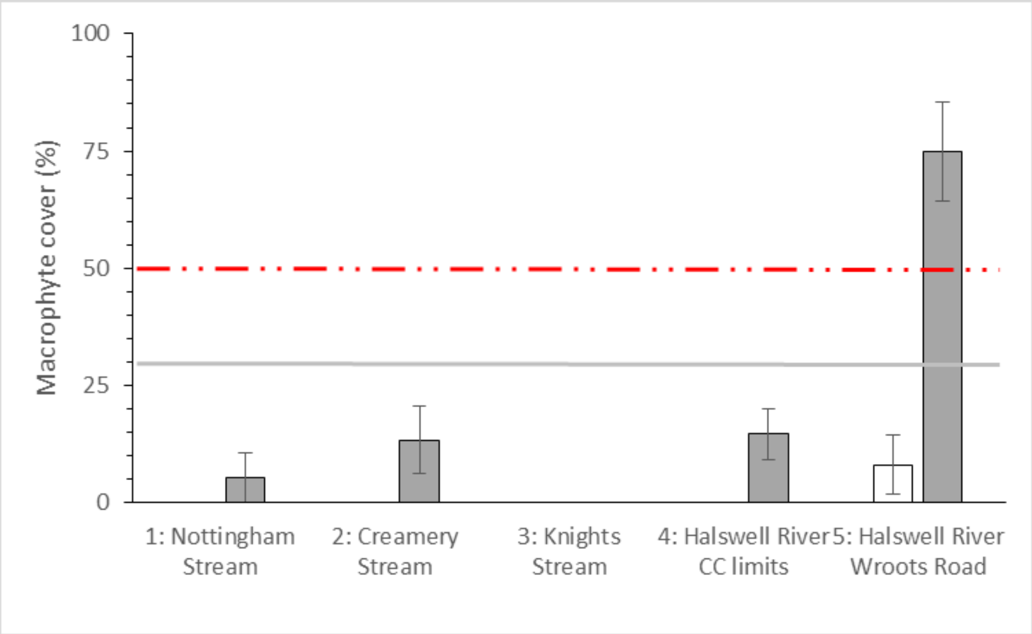

Figure 15. Mean (±1SE) macrophyte cover (emergent = white bars; total = grey bars) recorded at five locations along each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016. The grey line indicates the LWRP guideline for 'spring-fed – plains waterways' of 30% cover of emergent macrophytes; the red dashed line is the maximum total cover of macrophytes (emergent and submerged) recommended in the SWSMP consent surface water quality objectives.

Filamentous algae

Long (>20 mm) filamentous algae was rare in, or absent from, most sites surveyed, with the greatest total cover estimated in Site 1: Nottingham Stream (Figure 16). However, total filamentous algal cover in all sites surveyed was below the SWSMP guideline of 30% (maximum) cover.

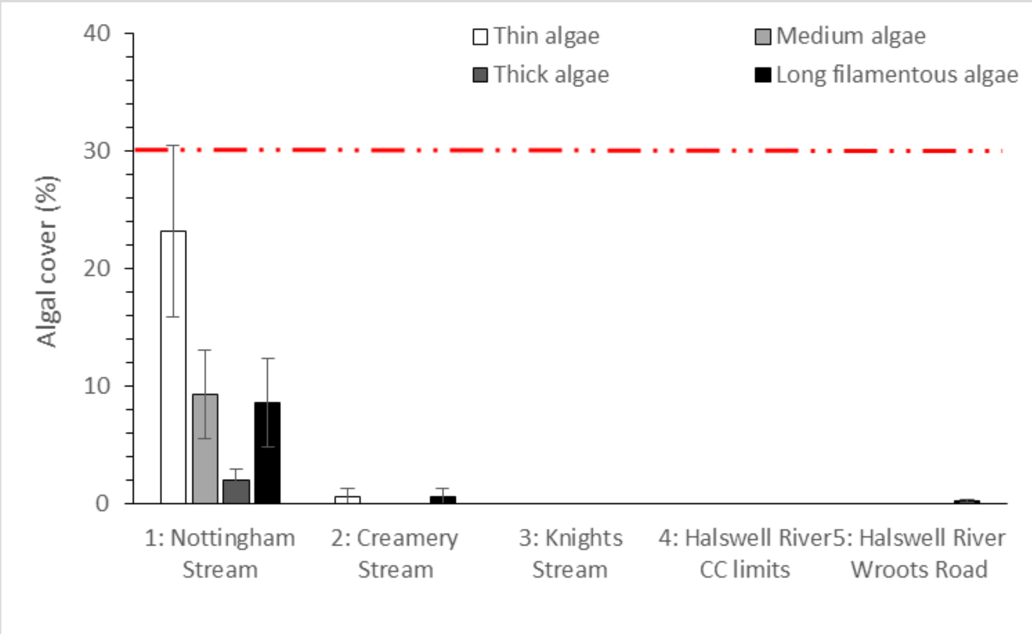

Figure 16. Mean (±1SE) algal cover recorded at five locations along each of three transects at the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016. The red dashed line is the maximum total cover of filamentous algae cover recommended in the SWSMP consent surface water quality objectives.

Sediment quality

Table 5 provides a summary of the grain size (%) composition found in the sediment sample collected from each site. The two Halswell River sites (Sites 4 & 5) had a greater proportion of very small (<0.063 mm) substrata, compared to the other three sites. Full sediment analysis results are provided in Appendix 1.

This result is of interest because metal contaminants are usually found in higher concentrations in sediment samples with the higher silt and clay contents (i.e. substrata <0.063 mm in size), as the greater surface area of smaller particles increases the absorption. This is particularly relevant as higher metal concentrations at a site may primarily be driven by a higher proportion of small particles (i.e. better attachment of the metals).

Total recoverable copper, lead, and zinc for all sites were below the ISQG-high and ISQG-low of the ANZECC (2000) sediment quality guidelines (Table 5). Where the sediment concentration is below the ISQG-low, it is considered that there is low risk of adverse effects to aquatic life.

The detected concentration of lead in sediment collected from Site 4: Halswell River CC limits approached the ISQG-low but did not exceed it. The lead concentration detected at this site was more than twice that of Site 1: Nottingham Stream and Site 2: Creamery Stream, and 4-6 times greater than that detected in the two Halswell River sites (Sites 4 & 5) (Table 5). Similarly, the zinc concentration detected at Site 1: Nottingham Stream was the greatest concentration of all sites, and although it approached the ISQG-low for zinc, it did not exceed it (Table 5). The two

Halswell River (Sites 4 & 5) sites had zinc concentrations around half of that detected at Site 1: Nottingham Stream, while much lower levels were detected in Site 2: Creamery Stream and Site 3: Knights Stream.

Total PAHs of all sites, normalised to 1% TOC (as recommended in ANZECC 2000), were also well below the ISQG-high and ISQG-low guidelines of the ANZECC (2000) sediment quality guidelines.

Moreover, the metal and PAH concentrations detected at all sites were comparatively low when considering concentrations detected in other waterways around Christchurch (e.g. Heathcote River catchment, Avon River catchment; Kingett Mitchell Ltd 2005; NIWA 2014, 2015).

SVOCs were also found in very low concentrations, and below laboratory detection limits, at all sites (Table 5). The presence of the SVOCs presented in Table 5 are generally indicators of waterways with degrading plastic rubbish within them, or waterways receiving discharge contaminated with wood, coal, and petroleum products.

There are no listed ANZECC (2000) guidelines for total phosphorus or total organic carbon. However, the levels measured in the Halswell River SWSMP catchment sites (this study) were similar, if not below, the levels detected in the nearby Heathcote River catchment sites (NIWA 2015).

Table 5. Particle size distribution (%),copper, lead, and zinc, total organic carbon, total phosphorus, total polycyclic aromatic hydrocarbons (PAHs), and semi-volatile organic compounds (SVOCs) in the sediment samples, March 2016. Copper, lead, zinc, and PAHs recorded by Kingett Mitchell Ltd (2005) are given in parentheses. Where more than one 2005 site was used for comparison, both values are given. *Total PAHs were normalised to 1% of TOC, as recommended by ANZECC (2000).

	Site 1: Nottingham Stream	**Site 2: Creamery Stream**	**Site 3: Knights Stream**	**Site 4: Halswell River CC limits**	**Site 5: Halswell River Wroots Road**	**ANZECC (2000) guideline**	
						ISQG-low	**ISQG-high**
Grain size							
Silt / clay: <0.063 mm	1.6	8.6	7.4	38.8	27	-	-
Fine sand: 0.063 - 0.250 mm	35.3	45.5	65	42.4	69	-	-
Medium sand: 0.250 - 0.500 mm	11.5	11.3	24.5	14.9	2.8	-	-
Coarse sand: 0.500 - 2.00 mm	3.5	4.6	1.2	2.7	0.7	-	-
Gravel and cobbles: >2.00 mm	48.1	30	1.9	1.2	0.5	-	-
Copper (mg / kg)	6 (5.1-14.5)	5 (6.4)	3 (2.9)	7 (4.2-6.4)	5 (8.7)	65	270
Lead (mg / kg)	21 (23.2-38.8)	19.3 (14.4)	8.2 (6.04)	49 (9.69-12.8)	11.9 (20.6)	50	220
Zinc (mg / kg)	184 (150-219)	52 (58.1)	37 (37)	70 (52-79.2)	83 (77.8)	200	410
Total organic carbon (g / 100 g)	0.79	0.35	0.23	2.9	0.92	-	-
Total phosphorus (mg / kg)	460	450	290	770	480	-	-
Total PAHs (mg / kg)*	0.151 (0.759)	0.071 (0.728)	0.122 (0.361)	0.034 (0.183)	0.093 (0.764)	4	45
SVOCs (mg / kg)							
Bis(2-ethylhexyl)phthalate	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5		
Butylbenzylphthalate	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2		
Di-n-butylphthalate	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2		
Carbazole	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Dibenzofuran	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		

Overall best and worst site

The sediment contaminant concentrations were ranked from best (1) to worst (5) for each of the contaminants measured. All sites were ranked equally (1=) for the SVOCs as concentrations were below detection limits at all sites.

Site 3: Knights Stream was ranked as the best site overall (i.e. ranked first place across sediment contaminant concentrations (Table 6). Site 1: Nottingham Stream and Site 4: Halswell

River CC limits were ranked last equal, making these two sites the worst overall, based on sediment contaminant concentrations (Table 6). Nevertheless, it's important to remember that none of the sediment contaminants measured exceeded ANZECC (2000) guidelines.

Table 6. Concentrations of copper, lead, zinc, total organic carbon, total phosphorus, total poly aromatic hydrocarbons (PAHs), and semi-volatile organic compounds (SVOCs), have been ranked from 1 (best) to 5 (worst) for each of the five site surveyed in March 2016. These ranks were then summed to give a final rank, indicating which site scored best in sediment quality. *All sites were ranked as 1= for SVOCs as concentrations were all below detection limits.

	Site 1: Nottingham Stream	**Site 2: Creamery Stream**	**Site 3: Knights Stream**	**Site 4: Halswell River CC limits**	**Site 5: Halswell River Wroots Road**
Copper (mg / kg)	4	2=	1	5	2=
Lead (mg / kg)	4	3	1	5	2
Zinc (mg / kg)	5	2	1	3	4
Total organic carbon (g / 100 g)	3	2	1	5	4
Total phosphorus (mg / kg)	3	2	1	5	4
Total PAHs (mg / kg)	5	2	4	1	3
SVOCs*	1=	1=	1=	1=	1=
Sum of ranks	25	14	10	25	20
Final rank	**4=**	**2**	**1**	**4=**	**3**

Changes in sediment quality over time

Kingett Mitchell surveyed a number of sites in the Halswell River catchment in 2005, including similar (but not necessarily exactly the same) locations to the sites surveyed in this study. Generally, the concentrations of copper, lead, and zinc were similar in 2016 to those detected in 2005 (Kingett Mitchell Ltd 2005), except for in Nottingham Stream where copper and zinc were slightly higher in 2005 than 2016; lead was greater in 2016 than 2005 for Site 4: Halswell River at CC limits (Table 5). It's important to note, however, that the exact same sites were not surveyed in both 2005 and 2016, so some variability in these concentrations may be expected due to location in the waterway / catchment.

PAHs were detected in much concentrations in 2005 (Kingett Mitchell Ltd 2005) than in 2016 (this study). For example, in 2005 the Nottingham Stream site, near Site 1, was reported to have total PAH of 0.759 mg / kg, five-fold greater than the concentration detected in March 2016 (Table 5). Site 2: Creamery Stream had a concentration 10 times greater in 2005 than in 2016, while the two Halswell River sites had 5-8 fold greater concentrations in 2005 than 2016 (Table 5).

Importantly, with the exception of zinc in one of the two Nottingham Stream sites surveyed in 2005, all sediment contaminants measured in both 2005 and 2016 were below the ANZECC (2000) guidelines.

Macroinvertebrate community

Overview

A grand total of 15,901 macroinvertebrates, belonging to 34 taxonomic groups, was collected from the 5 sites surveyed within the Halswell River catchment and within the SWSMP in March 2016.

The most diverse group was the true flies (or two-winged flies, Diptera) with 12 different taxa recorded at the 5 sites. Caddisflies (Trichoptera) and snails and bivalves (Mollusca) were the next most diverse groups, with 9 and 4 different taxa, respectively, followed by crustaceans (2 taxa), and one taxon of each of flatworms (Platyhelminthes), damselflies (Odonata), nematodes (Nematoda), aquatic moths (*Hygraula nitens*, Lepidoptera), true bugs (*Sigara*, Hemiptera), aquatic worms (Oligochatea), and aquatic mites (Acarina).

Snails and bivalves (e.g. the ubiquitous New Zealand mud snail *Potamopyrgus antipodarium*, the introduced snails *Physella acuta* and *Gyraulus* sp., and the tiny freshwater clam *Sphaerium*) and crustaceans (e.g. the freshwater amphipod *Paracalliope fluviatilis*) dominated the macroinvertebrate community collected.

The freshwater amphipod *Paracalliope fluviatilis*, the snails *Potamopyrgus antipodarium* and *Physella acuta*, the tiny freshwater clam *Sphaerium*, and the cased caddisfly *Hudsonema* were found at all five sites surveyed.

Oligochaete worms were found at all sites except Site 5: Halswell River Wroots Road, while aquatic mites were found (in very low abundances) in all sites except Site 2: Creamery Stream.

Eleven macroinvertebrate taxa were found in very low numbers and only recorded from one site, including three caddisflies (*Psilochorema* [presumably *P. bidens*], *Polyplectropus puerilis*, *Oeconesus similis*) the waterboatman (*Sigara*; Hemiptera), seven true flies (Diptera: *Austrosimulium*, *Zelandotipula*, Tanytarsini, Muscidae, Hexatomini, Ceratopogindae), and the freshwater amphipod *Paraleptamphopus*.

Total abundance

Similar numbers of macroinvertebrates were collected from Nottingham, Creamery, and Knights Streams (Sites 1-3), compared with much greater total abundances found in the two Halswell River sites (Sites 4 and 5) (Figure 17). Total abundance ranged from 1,204 in Site 3: Knights Stream to 6,645 in Site 4: Halswell River CC limits.

The difference in total abundance between the three tributary waterways (Sites 1-3) and the two Halswell River sites was largely because a greater number of the relatively pollution tolerant mud snail *Potamopyrgus antipodarium* and freshwater amphipod *Paracalliope fluviatilis* collected from Sites 4 and 5.

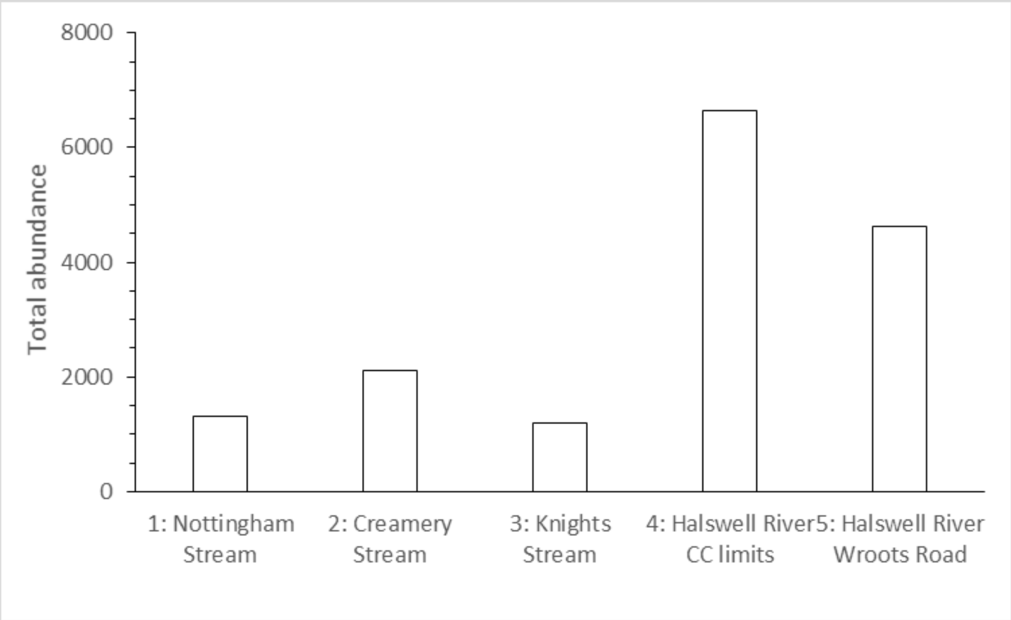

Figure 17. Total abundance of macroinvertebrates collected in a kick-net sample from each of the five sites surveyed in the Halswell River catchment and within the SWSMP in March 2016.

Taxonomic richness

Taxonomic richness was variable among sites, ranging from 13 to 22 macroinvertebrate taxa (Figure 18). Site 3: Knights Stream had the greatest taxonomic richness (22 taxa), followed by Site 2: Creamery Stream with 20 macroinvertebrate taxa. Site 1: Nottingham Stream (13 taxa) and Site 5: Halswell River Wroots Road (14 taxa) had the least diverse macroinvertebrate community.

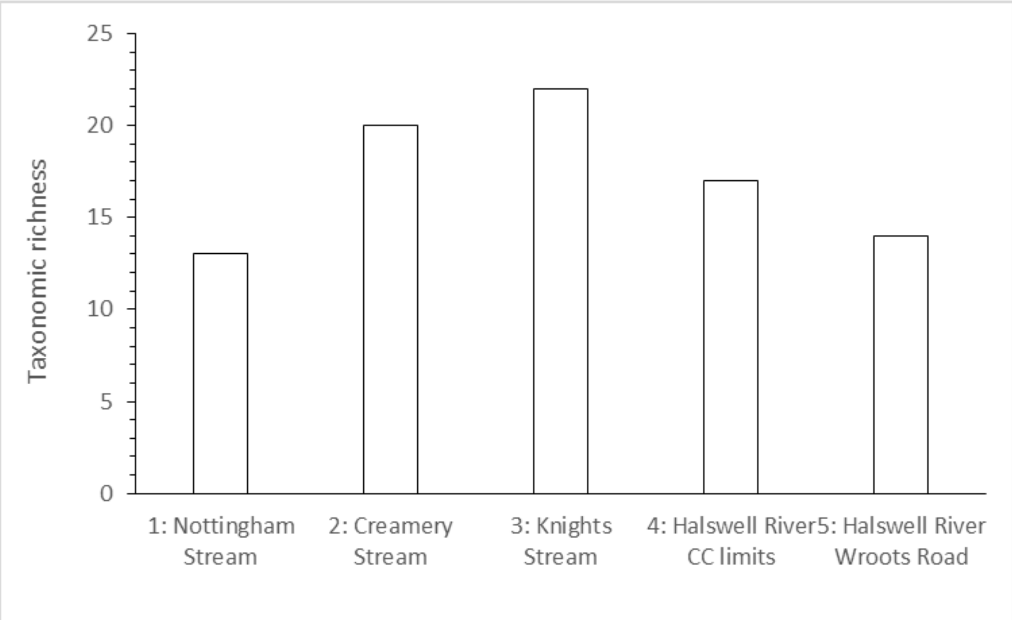

Figure 18. Taxonomic richness of macroinvertebrates collected in a kick-net sample from each of the five sites surveyed in the Halswell River catchment and within the SWSMP in March 2016.

EPT richness

The EPT insect orders (Ephemeroptera, mayflies; Plecoptera, stoneflies; and Trichoptera, caddisflies), which are generally sensitive to pollution and habitat degradation, are useful indicators of stream health. High EPT richness suggests high water and habitat quality, while low EPT richness suggests low water quality and degraded stream health.

EPT richness was relatively similar across the five sites, ranging from 6 taxa at Site 4: Halswell River CC limits to 3 EPT taxa at Site 1: Nottingham Stream and Site 5: Halswell River Wroots Road (Figure 19).

Caddisflies were the only group of clean-water 'EPT taxa' present in the Halswell River SWSMP catchment; mayflies and stoneflies were absent from all sites.

Although a total of nine caddisfly taxa were found in the five sites surveyed, five taxa (*Oecetis unicolor*, *Oeconesus similis*, *Polyplectropus puerilis*, *Psilochorema* [presumably *P. bidens*], and *Triplectides obsoletus*) were found at only one or two of the five sites.

The stick caddisflies *Hudsonema amabile* and *Triplectides cephalotes*, and the purse-cased caddisflies *Oxyethira albiceps* and *Paroxyethira hendersoni*[7] were encountered at 80-100% of the sites surveyed.

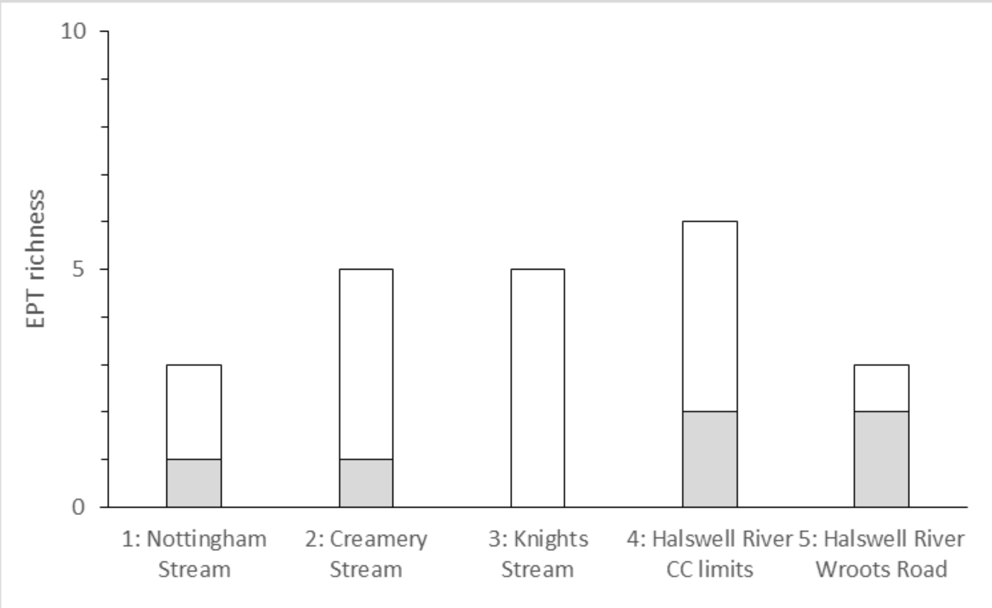

Figure 19. Total number of EPT taxa collected in a kick-net sample from each of the five sites surveyed in the Halswell River catchment and within the SWSMP in March 2016. White bars indicate EPT richness, while the grey bars indicate EPT richness minus the pollution-tolerant Hydroptilidae caddisflies.

Macroinvertebrate Community Index

Although there was some variability in MCI scores, all sites except Site 3: Knights Stream had "poor" stream health with "probable severe enrichment" (based on the water quality categories of Stark and Maxted 2007) (Figure 20). Site 3: Knights Stream was found to have "fair" stream health with "probable mild enrichment".

[7] *Paroxyethira hendersoni* and *Oxyethira albiceps* are both species of caddisflies belonging to the more pollution-tolerant family Hydroptilidae.

QMCI, which is considered a better indicator of "health" as it takes into account abundance and presence of macroinvertebrate taxa, showed a slightly different pattern, with Site 5: Halswell River Wroots Road having the greatest QMCI scores (Figure 19), indicating "fair" stream health with "probable mild enrichment". Site 3: Knights Stream and Site 4: Halswell River CC limits were on the cusp of "fair" stream health.

More importantly, only Site 5: Halswell River Wroots Road was above (but only marginally above) the SWSMP consent surface water quality objective of QMCI 4.5, while only Site 1: Nottingham Stream fell below the LWRP guideline for spring-fed (plains) urban waterways of a minimum QMCI of 3.5 (Figure 20).

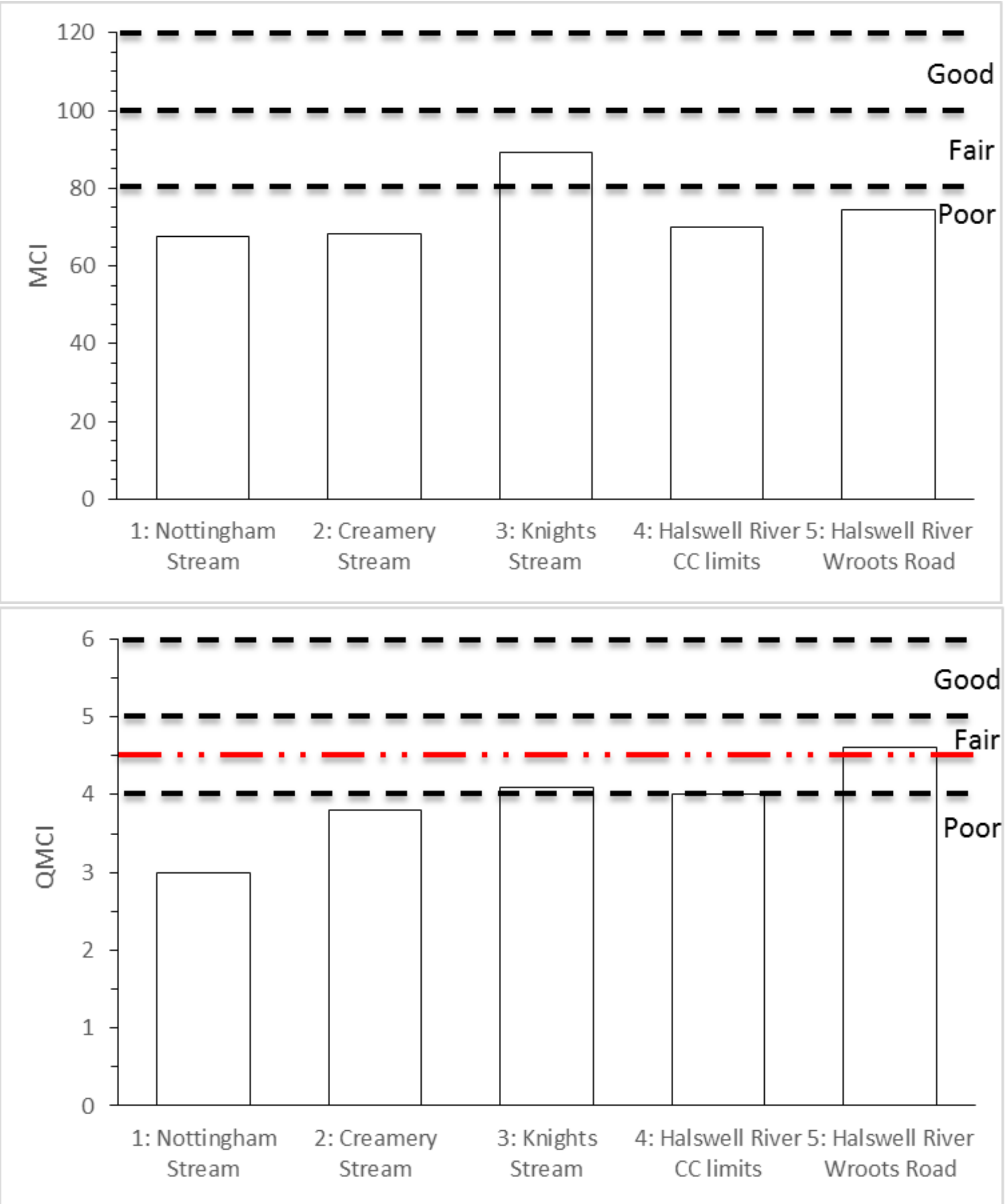

Figure 20. Macroinvertebrate Community Index (MCI) scores (top) and QMCI scores (bottom) for the five sites surveyed in the Halswell River catchment and within the SWSMP in March 2016. The dashed lines indicate the water quality categories of Stark and Maxted (2007), where "poor" = "probable severe enrichment", "fair" = "probable moderate enrichment", and "good" = "doubtful quality or possible mild enrichment". The "excellent" category has not been shown. The red line on the QMCI graph indicates the SWSMP consent surface water quality objective for the site.

Overall best and worst sites

When the biotic indices of taxonomic richness, EPT richness, %EPT richness, and QMCI scores, for each of the five sites surveyed, were ranked from 1 (best) to 5 (worst), Site 3: Knights Stream was ranked as the best site overall (i.e. ranked first place across all four indices (Table 7). This site had the greatest number of macroinvertebrate taxa, the second greatest number of EPT taxa, was ranked third in %EPT richness, and ranked second in the QMCI (Table 7). Site 2: Creamery Stream at Sabys Road was ranked the second best site overall, while Site 1: Nottingham Stream at O'Halloran Drive was ranked last, making it the worst site overall, based on these four biotic indices (Table 7).

Table 7. Taxonomic richness, EPT richness, %EPT richness, and QMCI values have been ranked from 1 (best) to 5 (worst) for each of the five site surveyed in March 2016. These ranks were then summed to give a final rank, indicating which site scored best out of these four biotic indices. Individual scores for each of the biotic indices are given in parentheses.

	Taxonomic richness	EPT richness	%EPT richness	QMCI	Sum of ranks	Final rank
Site 1: Nottingham Stream at O'Halloran Drive	5 (13)	4 (3)	2 (3.1)	5 (3.0)	16	5
Site 2: Creamery Stream at Sabys Road	2 (20)	2 (5)	1 (5.2)	4 (3.8)	9	2
Site 3: Knights Stream at 162 Whincops Road	1 (22)	2 (5)	3 (2.9)	2 (4.1)	8	1
Site 4: Halswell River at Christchurch City limits	3 (17)	1 (6)	4 (0.7)	3 (4.0)	11	3
Site 5: Halswell River at Wroots / Halswell Roads	4 (14)	4 (3)	5 (0.6)	1 (4.6)	14	4

Changes in macroinvertebrate community over time

Taxonomic richness and QMCI scores

Taxonomic richness and EPT richness was greater at all sites (except taxon richness) in 2016 (this study) than in 2011 (EOS Ecology 2011) (Figure 21).

There were also some noteworthy differences in QMCI scores between the 2011 (EOS Ecology 2011) and 2016 (this study) surveys. QMCI was generally greater in 2011, than in 2016, with the exception of Site 5: Halswell River Wroots Road (Figure 21). Nevertheless, most sites remained within the same water quality or stream health category; all sites were within the "poor" stream health category in 2011 (EOS Ecology 2011) and 2016 (this study) except Site 5: Halswell River Wroots Road, which was within the "poor" category in 2011, but marginally within the "fair" category in 2016.

It is important to note differences in sampling effort between the two sampling occasions, where in 2011 EOS Ecology collected three replicate kick-net samples from each site, while only one composite kick-net sample was collected from each site in 2016. However, this does not explain the greater number of EPT taxa, and macroinvertebrate taxa in general, collected in 2016, compared to 2011. It's also noteworthy that the 2011 survey (EOS Ecology 2011) was conducted only one month after the February 2011 Canterbury Earthquake, which may have been a significant factor in the apparent differences in macroinvertebrate and EPT richness between 2011 (one month after the February 2011 Canterbury Earthquake) and 2016 (5 years post-earthquakes).

However, QMCI can be highly variable through time, as abundances of macroinvertebrates can vary / change due to a range of disturbances including both natural (e.g. floods) and anthropogenic perturbations (e.g. nutrients / stormwater discharges). Moreover, the water-quality categories, as determined by QMCI, were not markedly different between 2011 and 2016, except for at Site 5: Halswell River Wroots Road.

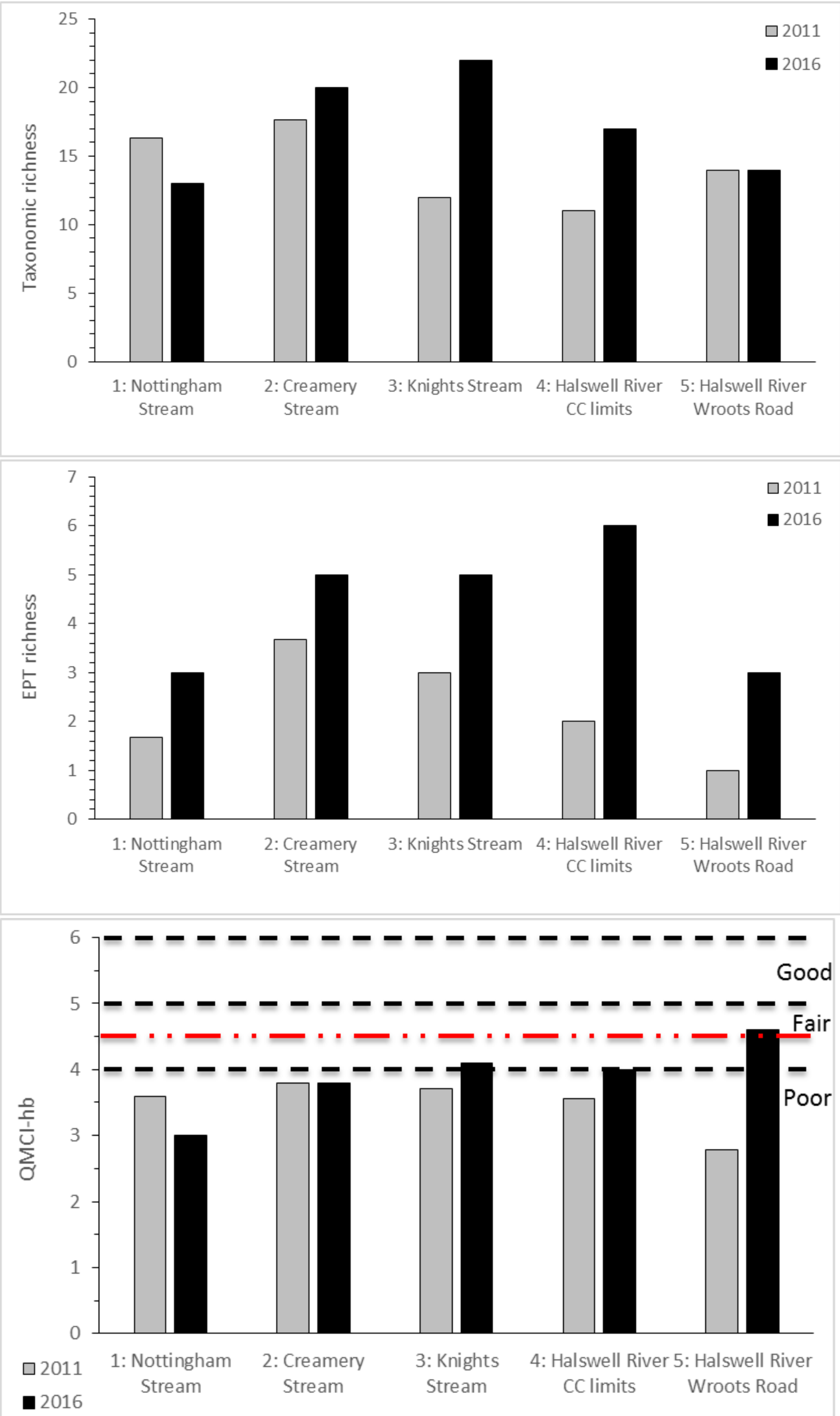

Figure 21. Taxonomic richness (top), EPT richness (middle), and QMCI scores (bottom) found at the five sites surveyed in 2011 (grey bars; EOS Ecology) and 2016 (black bars; this study). The dashed lines on the QMCI graph indicate the water quality categories of Stark and Maxted (2007), where “poor” = “probable severe enrichment”, “fair” = “probable moderate enrichment”, and “good” = “doubtful quality or possible mild enrichment”. The “excellent” category has not been shown. The red line indicates the SWSMP consent surface water quality objective of QMCI 4.5 for the site.

Community composition

Although there was some variability in macroinvertebrate community composition among the five sites and through time (2011 versus 2016), differences were largely due to variance in relative dominance (percent abundance) of snails and bivalves (Mollusca), crustaceans, true flies (Diptera), and 'other'. Caddisflies made up a very small proportion of the community at all sites in both 2011 (EOS Ecology) and 2016 (this study) (Figure 22).

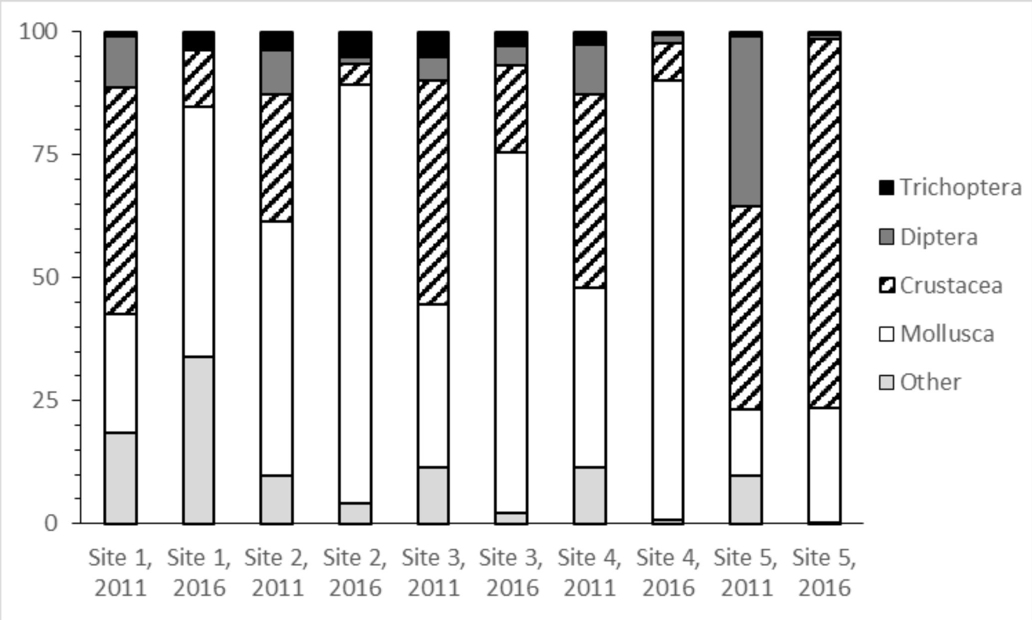

Figure 22. Macroinvertebrate community composition (%) found at the five sites surveyed in March 2011 (EOS Ecology) and March 2016 (this study). "Other" includes *Hydra* (Cnidaria), aquatic mites (Acarina), springtails (Collembolla), leeches (Hirudinea), waterboatmen (*Sigara*, Hemiptera), aquatic moths (*Hygraula nitens*, Lepidoptera), nematods (Nematoda), flatworms (Platyhelminthes) and damselflies (*Xanthocnemis zelandica*, Odonata).

Despite these subtle differences in relative abundances of the major macroinvertebrate groups (Figure 21), the NMDS ordination and ANOSIM results indicated that there was no significant difference in the macroinvertebrate communities found at the five sites (ANOSIM R = -0.05; P = 0.587) nor between years (ANOSIM R = 0.252; P = 0.480) (Figure 23).

SIMPER were not calculated as ANOSIM did not reveal any significant differences in macroinvertebrate community composition among sites or between years.

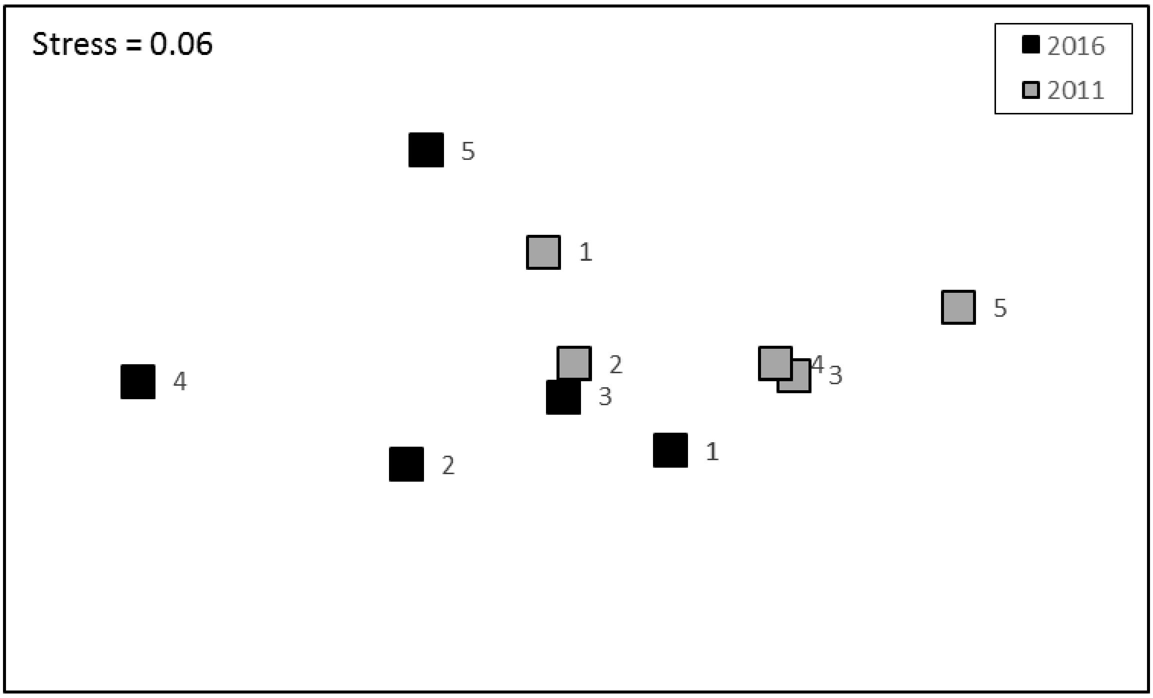

Figure 23. Non-metric multidimensional scaling (NMDS) ordination based on a Bray-Curtis matrix of dissimilarities calculated from macroinvertebrate abundance data collected from the five sites surveyed in March 2011 (grey squares; EOS Ecology 2011) and in March 2016 (black squares; this study). The NMDS ordination gave a good representation of the actual community dissimilarities between 2011 and 2016 (two-dimensional stress = 0.06). Axes are identically scaled so that sites closest together are more similar in macroinvertebrate composition, than those further apart. The significance of differences in community dissimilarity was confirmed using Analysis of Similarities (ANOSIM).

Fish community

Overview

A total of 397 fish, belonging to six species, were captured in the five sites surveyed within the Halswell River catchment and within the SWSMP in March 2016. The six species[8] were, in descending order of total abundance (i.e. across all sites): common bully (*Gobiomorphus cotidianus*), upland bully (*G. breviceps*), longfin eel (*Anguilla dieffenbachii*), shortfin eel (*A. australis*), inanga (*Galaxias maculatus*), and brown trout (*Salmo trutta*)[9].

Longfin eel and inanga have a conservation status of “at risk, declining”, while the remaining four freshwater fish species are currently listed as “not threatened” (Goodman et al. 2013).

Species richness

The fish communities were depauperate, with species richness generally around three to six fish species present at a site. Site 2: Creamery Stream had the most diverse freshwater fish community (6 species), four species were found at Site 1: Nottingham Stream, while the fewest

[8] Fish were recorded as bully species (*Gobiomorphus* sp.) and eel species (*Anguilla* sp.) when they were unable to be caught and / or identified to species level.

[9] Brown trout (*Salmo trutta*) is an introduced species of freshwater fish. All other species captured were native to New Zealand.

species (3) were detected at Site 3: Knights Stream and the two Halswell River sites (Sites 4 & 5).

Upland bullies and longfin eels were the most commonly encountered species, being found at all five sites. Common bullies were found at all sites except Site 3: Knights Stream. Shortfin eels were not found in the two Halswell River sites (Sites 4 & 5), while inanga and brown trout were only detected at Site 2: Creamery Stream (Table 8).

Size distribution of fish

Table 6 summarises the size and species richness information of fish captured (or seen but not captured) at the five sites surveyed in March 2016. The largest fish captured at any site was a 1,400 mm longfin eel at Site 5: Halswell River Wroots Road. Longfin eels (an “at risk, declining” species), which are less frequently found in the Heathcote and Avon River catchments, were found at all sites and in greater numbers than the “not threatened” shortfin eel.

Inanga were only detected at one site, Site 2: Creamery Stream, and both fish captured were 80 mm in length. It’s worth noting that the presence / abundance of inanga is underestimated by electric fishing techniques, so this species may have been more abundant in Creamery Stream than is shown in Table 6.

Table 8. Total number of fish caught (or seen) at each of the five sites surveyed in March 2016. Size (mm) ranges are shown in parentheses. Where the minimum and maximum size were the same, only one value is shown. *indicates fish that were not caught and size was unable to be measured or estimated. Different fishing methods were used in the two Halswell River sites. EF = electric fishing; traps = fyke nets and Gee minnow traps.

	Fishing method	Common bully	Upland bully[10]	Bully sp.	Longfin eel	Shortfin eel	Eel sp.	Inanga[11]	Brown trout
Site 1: Nottingham Stream at O’Halloran Drive	EF	1 (25)	66 (10-75)	50*	1 (180)	3 (120-650)		0	0
Site 2: Creamery Stream at Sabys Road	EF	1 (30)	13 (20-65)	2 (15-15)	15 (80-1000)	7 (120-400)	3 (150-200)	2 (80)	2 (300)
Site 3: Knights Stream at 162 Whincops Road	EF	0	15 (15-65)	12 (10-15)	3 120-300)	2 (150-250)	7 (400)	0	0
Site 4: Halswell River at Christchurch City limits	Traps	29 (30-110)	4 (40-65)		9 (450-1000)	0		0	0
Site 5: Halswell River at Wroots / Halswell Roads	Traps	131 (15-55)	5 (50-60)		14 (500-1400)	0		0	0

[10] Non-migratory bullies, such as upland bullies, can be underestimated by trapping (Joy et al. 2013).

[11] Inanga can be underestimated by electric fishing (Joy et al. 2013).

Community composition

While upland bullies and longfin eels were the most commonly encountered species, they did not always dominate the fish community (Figure 24). This was especially the case in the two Halswell River sites (Sites 4 & 5) where common bullies dominated the freshwater fish catch. However, upland bullies were an important (dominant) component of the fish community in Site 1: Nottingham Stream and Site 3: Knights Stream. The unidentified bullies from these two sites were likely to be upland bullies, but these individuals were either too small or were unable to be captured, and therefore could not be clearly identified.

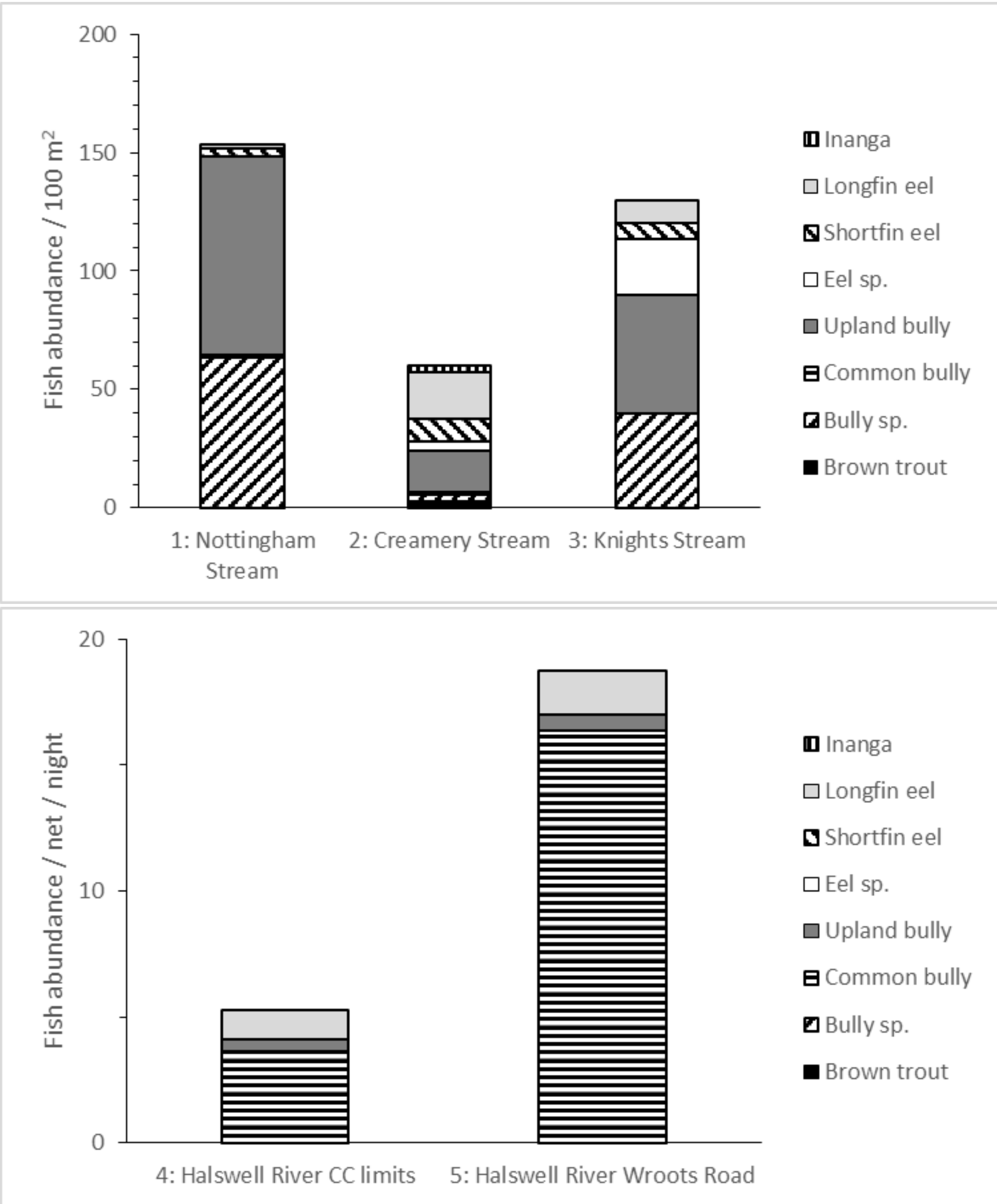

Figure 24. Total abundance of fish, separated by species, captured at each of the five sites surveyed in March 2016. Numbers are show as catch per unit effort (CPUE): per 100 m^2 of waterway surveyed using electric fishing (top); or per net / night where traps and nets were set overnight (bottom).

Changes in fish community over time

There was very little difference in fish species richness or community composition found at the three sites surveyed by Aquatic Ecology Ltd in 2011 and by Boffa Miskell (this study, 2016) (Table 9).

There were, however, some differences between the fish community found in 2016, compared to 2004 (CCC 2005) (Table 9). In particular, koura (*Paranephrops zealandicus,* freshwater crayfish, a crustacean not freshwater fish species, but is often caught during electric fishing) were not found in Creamery Stream in this study, nor was this species found by Aquatic Ecology Ltd in 2011 (referred to as Quaifes Drain in Aquatic Ecology Ltd 2011). However, the 2004 survey (CCC 2005) found this waterway to be an important breeding ground for koura. It is thought that the loss of (suitable habitat for) this species was a result of changes to in-stream habitat conditions as a result of the Canterbury earthquakes.

The Halswell River at CC limits (Site 4, this study) was not surveyed in 2011 (Aquatic Ecology Ltd 2011), but was surveyed in 2004 (CCC 2005). Upland bullies were found in 2016, but not in 2004; shortfin eel, inanga, and brown trout were found in 2004 but not in this study (2016) (Table 9).

Longfin eels were detected in greater numbers in 2016, than 2011 (Figure 25).

Fish abundance (CPUE) was also variable between the two survey years, with a greater number of fish detected at Site 1: Nottingham Stream and Site 3: Knights Stream in 2016, than 2011. The opposite trend was observed for Site 2: Creamery Stream, with a greater number of fish being captured / encountered in 2011, compared to 2016 (Figure 25).

Table 9. Fish species, including dominant species (based on abundance data), and richness found at three sites surveyed in this study (Boffa Miskell 2016) and previous work commissioned by the Christchurch City Council (Aquatic Ecology Ltd 2012 and CCC 2005). Species shown in bold were found in one survey, but not detected in the others.

Site name / number	Species found in 2016 (Boffa Miskell 2016)	Species found in 2011 (Aquatic Ecology Ltd 2011)	Species found in 2004 (CCC 2005)
Site 1: Nottingham Stream at O'Halloran Drive	Dominant species: upland bully, unidentified bully Upland bully, common bully, longfin eel, shortfin eel *(single-pass electric fishing)* Richness = 4	Dominant species: upland bully Upland bully, common bully, longfin eel, shortfin eel *(single-pass electric fishing)* Richness = 4	Site 20 Shortfin eel, upland bully Richness = 2
Site 2: Creamery Stream at Sabys Road	Dominant species: longfin eel, upland bully Upland bully, **common bully**, longfin eel, shortfin eel, inanga, brown trout *(single-pass electric fishing)* Richness = 6	Dominant species: Upland bully Upland bully, longfin eel, shortfin eel, inanga, brown trout *(single-pass electric fishing)* Richness = 4, plus koura	Site 11 Upland bully, **perch**, **koura** Richness = 2 + koura
Site 3: Knights Stream at 162 Whincops Road	Dominant species: upland bully Upland bully, longfin eel, shortfin eel *(single-pass electric fishing)* Richness = 3	Dominant species: upland bully Upland bully, longfin eel, shortfin eel *(single-pass electric fishing)* Richness = 3	Site 12 Upland bully Richness = 1
Site 4: Halswell River at Christchurch City limits	Dominant species: common bully Common bully, **upland bully**, longfin eel Richness = 3	Not surveyed	Site 26 **Shortfin eel**, longfin eel, common bully, **inanga**, **brown trout** Richness = 5

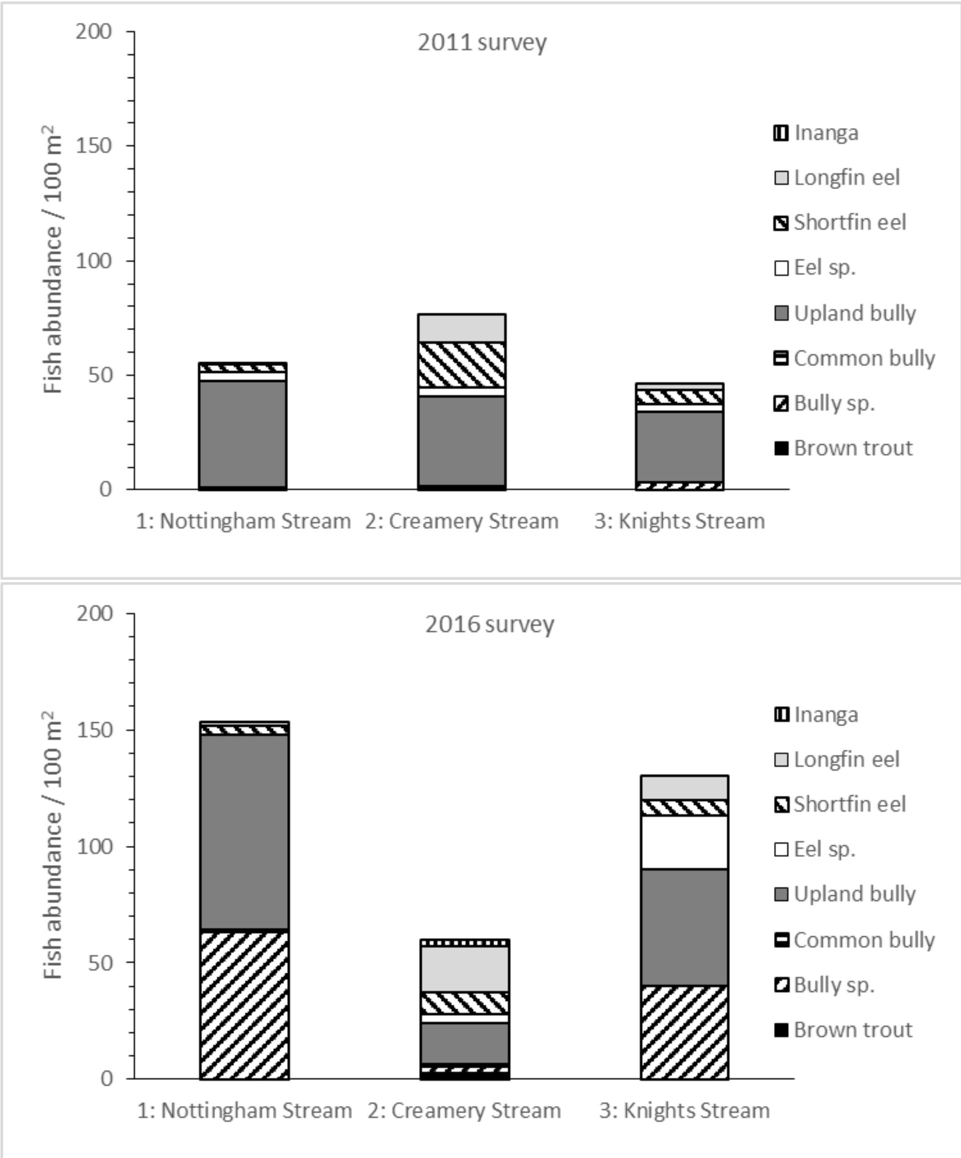

Figure 25. Total abundance of fish, separated by species, captured at each of the three sites surveyed in 2011 (Aquatic Ecology Ltd 2012) and in 2016 (this study). Numbers are show as catch per unit effort (CPUE): per 100 m^2 of waterway surveyed using electric fishing (top).

Discussion

Ecosystem health

This ecological assessment indicated that the sites surveyed within the Halswell River catchment were generally of poor ecological health. Of the five sites surveyed, only one (Site 5: Halswell River Wroots Road) fell within the "fair" water quality category. The remainder of sites surveyed were classified as "poor", with probable severe enrichment. Site 3: Knights Stream and Site 4: Halswell River CC limits were on the cusp of the "fair" water quality category. Moreover, only Site 5: Halswell River Wroots Road was above the SWSMP consent surface water quality objective of a minimum QMCI 4.5, however, only Site 1: Nottingham Stream fell below the LWRP guideline for spring-fed (plains) urban waterways of a minimum QMCI of 3.5. These findings are similar to that of the recent study within the Heathcote River catchment, where 84% of sites surveyed fell within the "poor" water quality category (Boffa Miskell 2015).

Nevertheless, water and habitat quality, sediment contaminant concentrations, and the macroinvertebrate and fish community needs to be considered when looking at the overall ecological health of a site, or waterway.

A noteworthy finding was that when sites were ranked according to: a) sediment contaminant concentrations; and b) the four biotic indices, Site 3: Knights Stream and Site 2: Creamery Stream were found to be the best sites overall. Site 1: Nottingham Stream was scored as the worst site for both sediment contaminant concentrations and macroinvertebrate biotic indices.

Water quality

The basic water quality parameters of conductivity, pH, dissolved oxygen, and water temperature were within ranges expected in spring-fed urban environments during base-flow conditions. Conductivity levels recorded were generally similar to those recorded in the Heathcote River and Avon River catchments in 2013 and 2015, respectively (Boffa Miskell 2014; 2015). pH was generally circum-neutral in all five sites and, at the time of sampling, fell within the water quality standard for receiving waters of the LWRP. Dissolved oxygen levels were relatively high at all sites, except Nottingham Stream (Site 1) and Knights Stream (Site 3), both of which, at the time of sampling, had very low water levels and velocity, due to unseasonably dry weather over the 2015/2016 summer. Water temperature was generally cool at all sites, and all were below the LWRP guideline of 20°C for Canterbury Rivers.

It is important to note, however, that these water quality parameters were measured only on one occasion at each site. Spot readings do not take into account the diurnal and seasonal variability in water chemistry and temperature, and the macroinvertebrate community is a much better indicator of long-term stream, or ecosystem, health.

Riparian and in-stream habitat

Riparian and in-stream conditions, although variable among sites, were generally degraded and found to be generally similar to that of previous surveys. Substrate indexes were low at all sites, indicating stream-bed substrates were dominated by finer particles and generally lacking in boulders and large cobbles. Site 1: Nottingham Stream had the coarsest stream-bed substrata, dominated by cobbles and gravels, compared to the silt/sand dominated beds of all the other sites. Fine sediment (<2 mm diameter) covered between 50% and 100% of the stream bed at all sites, which exceeded the SWSMP consent surface water quality objective of a maximum cover of 40%. Not only did sediment cover a high proportion of the stream bed, but it was also very thick in many of the sites. All of these factors meant that when coarser substrata were present (e.g. cobbles) these were highly embedded and generally unavailable to aquatic biota (for grazing, egg laying, using as refugia).

Overhanging vegetation and undercut banks, which provide shading and habitat for in-stream fauna (e.g. fish), were uncommon. Canopy cover, and therefore stream shading, was variable at Nottingham, Creamery, and Knights stream and entirely absent in the two Halswell River sites.

Macrophyte and filamentous algal cover was generally low across all sites[12], except in Site 5: Halswell River Wroots Road where extensive beds of the commonly occurring exotic species curly pondweed and Canadian pondweed were found.

Sediment quality

Sediment contaminant concentrations were variable across sites for the parameters measured. When all sites were compared, Site 3: Knights Stream was considered to be the best site in regards to the sediment contaminants analysed. Site 1: Nottingham Stream and Site 4: Halswell River CC limits were ranked as the worst sites.

However, concentrations never exceeded ANZECC (2000) guidelines, where available. Moreover, the metal and PAH concentrations detected at all sites were comparatively low when considering concentrations detected in the Heathcote River and Avon River catchments (NIWA 2014; 2015) and when compared to previous measures at similar sites within the Halswell River catchment (Kingett Mitchell Ltd 2005).

Macroinvertebrate community

The macroinvertebrate community of the Halswell River catchment sites were dominated by taxa typical of lowland urban and rural waterways, such as chironomid midges, snails, oligochaete worms, and amphipods. Although there were some subtle differences in macroinvertebrate community composition, the community found in this study was similar to that found in 2011 (EOS Ecology 2011). The pollution-sensitive or “clean-water” EPT taxa were represented by more tolerant caddisflies (a total of nine caddisfly taxa, with a maximum of 6 taxa found at any one site), while the more sensitive mayflies and stoneflies were absent. The more “pollution-tolerant” hydroptilid caddisflies, *Oxyethira albiceps* and *Paroxyethira hendersoni*, were found at the majority of sites.

When ranked according to four biotic indices, Site 3: Knights Stream was considered the best site overall, while Site 2: Creamery Stream was ranked second best, and Site 5: Halswell River Wroots Road and Site 1: Nottingham Stream were ranked as the worst sites overall. This was in line with the ranking of sites according to sediment contaminant concentrations, where Site 3: Knights Stream was ranked as the best site overall, while Site 1: Nottingham Stream, Site 4: Halswell River CC limits, and Site 5: Halswell River Wroots Road were the ranked as the worst sites.

[12] Macrophytes are periodically cleared from Christchurch’s waterways for drainage purposes. However, all sites were surveyed prior to macrophyte clearance, and at some sites this practice had not been done for a number of months / years.

Macroinvertebrates are an important and commonly used measure of stream, or ecosystem, health and this survey showed that all sites had “poor” to “fair” water quality with probable severe or mild enrichment.

Fish community

It is important to remember that although the sites surveyed in this study were classified as having “poor” or “fair” water quality (based on the macroinvertebrate community present [QMCI]), native fish species were present at these sites. Most importantly, all sites supported longfin eels, an “at risk, declining” species. Inanga, another “at risk, declining” species was also found in the catchment (Site 2: Creamery Stream) and, although it was not encountered in the two Halswell River sites surveyed in this study, this species is known to be present in various parts of Halswell River.

Giant bullies, which are often encountered in urban waterways around Christchurch, were not found in any of the sites surveyed in this study. This may be a reflection of the lack of undercut bank and limited availability of overhanging vegetation, as well as the shallow nature of Nottingham and Knights Streams. Giant bullies have relatively specific habitat preferences, tending to occur in deeper, slow water generally found along river margins (e.g. undercut banks).

The fish community does not appear to have markedly changed over time, when comparing results from 2004 (CCC 2005), 2011 (Aquatic Ecology Ltd 2012), and 2016 (this study). There were few species that were found during one survey but not in the other/s: common bullies were found at Site 2: Creamery Stream in 2016, but not found in 2011; kōura (the freshwater crayfish – a crustacean not freshwater fish species, but is often caught during electric fishing) was found in Creamery Stream in 2005 (CCC 2005) but not in 2016; shortfin eel, inanga, and brown trout were captured in Halswell River CC limits (Site 4) in 2004, but not in 2016 (this study), while upland bullies were found in 2016, but not in 2004 (CCC 2005).

Baited fyke nets were used to survey the fish community in Halswell River CC limits in both 2016 and 2004. However, electric fishing of the margins was also used in 2004, but not in 2016. These differences in fish composition may be a reflection of the additional electric fishing in 2004, but also due to unavoidable variation often found when fish composition is surveyed using a single night’s trapping effort.

It is noteworthy that perch were recorded in Creamery Stream (Quaifes Drain) in 2004 (CCC 2005), but were not found in 2011 (Aquatic Ecology Ltd 2011) nor in 2016 (this study) (Table 9). Perch are known to occur in the lower Halswell River, and the spring-fed waterways of Creamery Stream / Quaifes Drain have been noted to provide suitable rearing habitat for this species. Perch are known to become piscivorous (fish eaters) at a larger size.

The apparent absence of kōura may well be as a result of adverse changes to in-stream habitat conditions in Creamery Stream, as a result of the Canterbury earthquakes (Aquatic Ecology Ltd 2012).

Kōura is of conservation interest as it is listed as “at risk, declining”. Kōura are known from only a few of Christchurch’s waterways today, and tend to be most abundant in the less urbanised areas, such as Cashmere Stream (EOS Ecology 2013a). Kōura are thought to have declined in Canterbury’s waterways due to land use change, and particularly effects of urbanisation such as removal / alteration of habitat conditions essential for kōura survival (e.g. earth banks for burrowing into, debris clusters, and macrophytes for refugia).

The general lack of differences in the fish community (with the exception of the freshwater crayfish, kōura) between 2011 and 2016 is interesting given that the 2011 study was conducted only a few months after the February 2011 Canterbury Earthquake. It is plausible that fewer species could have been expected to be found in 2011 due to mortality, movement out of a site, etc, as a result of effects by earthquakes on the waterways. However, the community appears to be unchanged in 2016, more than five years after the main disturbances from these earthquakes. The apparent loss of kōura from Creamery Stream, presumably as a result of disturbances due to the Canterbury earthquakes, is the most marked difference in the freshwater community.

Effects of urbanisation

The effects of urbanisation on stream ecosystems are complex, and often there are multiple and interrelated stressors at play. It's not always straightforward to determine the main drivers responsible for loss of 'sensitive, clean water' taxa. However, one of the main drivers of changes in community composition in urban systems is the amount of impervious surfaces and untreated stormwater discharged through an open stormwater network. Untreated stormwater brings with it fine sediments and contaminants, which can then smoother the stream bed or be directly consumed by freshwater fauna.

Large cobbles and emergent and submerged boulders are also often limited or entirely absent from urban waterways. A variety of bed substrates, including large cobbles and boulders are important for egg-laying surfaces for fish and aquatic insects. Many freshwater insects have specific oviposition (egg-laying) requirements; some caddisfly species deposit eggs masses on the undersides of boulders in stream channels, while others specifically select emergent boulders, with specific downstream water velocities for oviposition sites. The size of the emergent boulder is important to some species, while others, it's the downstream water velocity that is most critical (Reich and Downes 2003). The successful recruitment of aquatic insect species, which in turn provide food sources for many of New Zealand's native freshwater fishes, is partly dependent on the availability of suitable oviposition habitat.

Moreover, the straightening and channelizing of urban waterways to improve the drainage capacity and efficiency has marked consequences on in-stream habitat and the macroinvertebrate and fish communities. Regular maintenance, or removal, of macrophyte beds also undoubtedly has negative impacts on the ecology of waterways. When macrophytes are mechanically removed, sediments are re-suspended, which affects water quality (e.g. turbidity and dissolved oxygen), and in-stream habitat is lost.

In-stream habitat heterogeneity (including availability of a variety of habitats such as macrophyte beds, woody debris, log jams, leaf packs, and stable undercut banks) is essential for maintaining the health of a waterway and supporting diverse macroinvertebrate and fish communities. A diversity of in-stream habitat can be rare in urban waterways, and particularly in those that are regularly maintained for flood conveyance purposes.

Studies have also shown that both freshwater fishes and adult aquatic insects often face a number of anthropogenic barriers to dispersal in urban environments, which can all have implications for recruitment. For example, piped stormwater inputs can bring pollutants that may act as chemical barriers to fish passage in streams. Road culverts can also alter the physical habitat of a stream (e.g. velocity, connectivity along the stream [perched culverts]), affecting fish and macroinvertebrate passage (Boubee et al. 1999; Resh 2005). While road crossing (especially culverts), light pollution (many of our caddisfly species are nocturnal), and the probable confusion of the built environment (e.g. concrete, which when wet reflects polarised light that confuses insects; tall buildings with few riparian 'markers' for species to navigate along and between waterways) may all disrupt adult aquatic insect flight (see discussion in Blakely et al. 2006).

Recommendations

- There needs to be a multi-faceted approach to the management of Christchurch's urban waterways. For example, a continued focus should be on both treatment of stormwater and habitat rehabilitation activities.
- Stormwater management needs to continue to focus on reducing the quantity of sediment and contaminant inputs into the catchment. This may include retrofitting of existing drainage and stormwater connections, where possible.
- Best practice stormwater management techniques need to be employed in areas of future residential and urban development, particularly in areas where ecological health is greatest and threatened species and species rare to Christchurch still occur.
- Areas of greatest ecological health need to be maintained through appropriate management activities, while areas of lower health could be improved over time through intensive management of stormwater and contaminated sediments, and riparian and in-stream enhancements.
- Enhancement of riparian and in-stream habitat conditions, particularly in areas where the existing habitat is especially poor. For example, the two Halswell River sites had no canopy cover, a general absence of stable undercut banks and overhanging vegetation, and were limited in variety of in-stream habitat. Fish diversity was lowest in the two Halswell River sites.
  - Canopy cover provides shading of the stream, which helps reduce excessive macrophyte growth, provides organic (leaf litter) resources for the macroinvertebrate community, and helps regulate water temperature and dissolved oxygen levels.
  - Stable undercut banks and overhanging vegetation provide important habitat and refugia for aquatic fauna, particularly freshwater fishes.
  - Include a variety of larger substrates (e.g. emergent and submerged boulders, debris clusters, macrophyte beds) in habitat enhancement activities, particularly to increase the availability of egg-laying habitats for fish and macroinvertebrates, refugia for freshwater fauna (e.g. fish habitat / hotels).
  - Consider options to remove some of the excessive soft / fine sediment cover in some waterways. This option needs to be conducted in conjunction with suitable stormwater management (i.e. to stop / reduce sediments entering the waterways), and is best conducted along the length of a waterway rather than only at a local site.
- Consider assessing the effects of the current macrophyte and stream maintenance practices to reduce likely disturbance to in-stream fauna. Increased riparian planting, and therefore, stream shading may be a better control of excessive macrophyte growth in urban streams.
- Use ecologically sensitive species when conducting riparian planting activities, including locally-sourced native species, and preferably evergreen, so as to provide organic

resources to the stream, but in a timely fashion (i.e. to avoid overwhelming streams with leaf litter inputs from deciduous trees in the autumn).

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Appendix 1: Sediment contaminant concentrations

Hill Laboratories

BETTER TESTING **BETTER RESULTS**

R J Hill Laboratories Limited
1 Clyde Street
Private Bag 3205
Hamilton 3240, New Zealand

Tel +64 7 858 2000
Fax +64 7 858 2001
Email mail@hill-labs.co.nz
Web www.hill-labs.co.nz

ANALYSIS REPORT

Client:	Boffa Miskell Limited	**Lab No:**	1557609 SPv1
Contact:	Tanya Blakely	**Date Registered:**	26-Mar-2016
	C/- Boffa Miskell Limited	**Date Reported:**	21-Apr-2016
	PO Box 110	**Quote No:**	74670
	Christchurch 8140	**Order No:**	
		Client Reference:	Boffa Miskell Job# C16010
		Submitted By:	Tanya Blakely

Sample Type: Sediment

Sample Name:		Site 1 Nottingham 22-Mar-2016 10:00 am	Site 2 Creamery 22-Mar-2016 12:00 pm	Site 3 Knights 22-Mar-2016 2:00 pm	Site 4 Halswell City Limits 21-Mar-2016 12:30 pm	Site 5 Haswell Wroots 21-Mar-2016 3:45 pm
Lab Number:		1557609.1	1557609.2	1557609.3	1557609.4	1557609.5
Individual Tests						
Dry Matter	g/100g as rcvd	81	77	66	42	63
Fraction >/= 500 µm*	g/100g dry wt	51.6	34.6	3.1	3.9	1.2
Fraction >/= 250 µm*	g/100g dry wt	63.1	45.9	27.6	18.7	4.0
Total Recoverable Copper	mg/kg dry wt	6	5	3	7	5
Total Recoverable Lead	mg/kg dry wt	21	19.3	8.2	49	11.9
Total Recoverable Phosphorus	mg/kg dry wt	460	450	290	770	480
Total Recoverable Zinc	mg/kg dry wt	184	52	37	70	83
Total Organic Carbon*	g/100g dry wt	0.79	0.35	0.23	2.9	0.92
7 Grain Sizes Profile						
Dry Matter	g/100g as rcvd	79	76	61	48	65
Fraction >/= 2 mm*	g/100g dry wt	48.1	30.0	1.9	1.2	0.5
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	1.7	2.9	0.4	0.9	0.3
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	1.8	1.7	0.8	1.8	0.4
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	11.5	11.3	24.5	14.9	2.8
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	31.5	34.4	51.0	21.5	27.0
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	3.8	11.1	14.0	20.9	42.1
Fraction < 63 µm*	g/100g dry wt	1.6	8.7	7.4	38.8	27.0
Polycyclic Aromatic Hydrocarbons Trace in Soil						
Acenaphthene	mg/kg dry wt	< 0.002	< 0.002	< 0.003	< 0.004	< 0.003
Acenaphthylene	mg/kg dry wt	< 0.002	< 0.002	< 0.003	< 0.004	< 0.003
Anthracene	mg/kg dry wt	< 0.002	< 0.002	< 0.003	< 0.004	< 0.003
Benzo[a]anthracene	mg/kg dry wt	0.005	< 0.002	< 0.003	0.005	0.004
Benzo[a]pyrene (BAP)	mg/kg dry wt	0.008	< 0.002	< 0.003	0.007	0.007
Benzo[b]fluoranthene + Benzo[j] fluoranthene	mg/kg dry wt	0.013	0.003	< 0.003	0.010	0.011
Benzo[g,h,i]perylene	mg/kg dry wt	0.006	< 0.002	< 0.003	0.006	0.007
Benzo[k]fluoranthene	mg/kg dry wt	0.004	< 0.002	< 0.003	0.004	0.003
Chrysene	mg/kg dry wt	0.009 #1	< 0.002	< 0.003	0.006	0.006
Dibenzo[a,h]anthracene	mg/kg dry wt	< 0.002	< 0.002	< 0.003	< 0.004	< 0.003
Fluoranthene	mg/kg dry wt	0.021	0.002	< 0.003	0.014	0.012
Fluorene	mg/kg dry wt	< 0.002	< 0.002	< 0.003	< 0.004	< 0.003
Indeno(1,2,3-c,d)pyrene	mg/kg dry wt	0.007	0.002	< 0.003	0.006	0.006
Naphthalene	mg/kg dry wt	< 0.010	< 0.010	< 0.011	< 0.017	< 0.011
Phenanthrene	mg/kg dry wt	0.017	< 0.002	< 0.003	0.009	0.006
Pyrene	mg/kg dry wt	0.019	0.002	< 0.003	0.014	0.011
Haloethers Trace in SVOC Soil Samples by GC-MS						

Sample Type: Sediment						
Sample Name:		Site 1 Nottingham 22-Mar-2016 10:00 am	Site 2 Creamery 22-Mar-2016 12:00 pm	Site 3 Knights 22-Mar-2016 2:00 pm	Site 4 Halswell City Limits 21-Mar-2016 12:30 pm	Site 5 Haswell Wroots 21-Mar-2016 3:45 pm
Lab Number:		1557609.1	1557609.2	1557609.3	1557609.4	1557609.5
Haloethers Trace in SVOC Soil Samples by GC-MS						
Bis(2-chloroethoxy) methane	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Bis(2-chloroethyl)ether	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Bis(2-chloroisopropyl)ether	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
4-Bromophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
4-Chlorophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Nitrogen containing compounds Trace in SVOC Soil Samples, GC-MS						
N-Nitrosodiphenylamine + Diphenylamine	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
2,4-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
2,6-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nitrobenzene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
N-Nitrosodi-n-propylamine	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
Aldrin	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
alpha-BHC	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
beta-BHC	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
delta-BHC	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
gamma-BHC (Lindane)	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
4,4'-DDD	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
4,4'-DDE	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
4,4'-DDT	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Dieldrin	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Endosulfan I	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Endosulfan II	mg/kg dry wt	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Endosulfan sulphate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Endrin	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
Endrin ketone	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Heptachlor	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Heptachlor epoxide	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Hexachlorobenzene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Polycyclic Aromatic Hydrocarbons Trace in SVOC Soil Samples						
Acenaphthene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Acenaphthylene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Anthracene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Benzo[a]anthracene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Benzo[a]pyrene (BAP)	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Benzo[b]fluoranthene + Benzo[j] fluoranthene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Benzo[g,h,i]perylene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Benzo[k]fluoranthene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
1&2-Chloronaphthalene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Chrysene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Dibenzo[a,h]anthracene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Fluoranthene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Fluorene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Indeno(1,2,3-c,d)pyrene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
2-Methylnaphthalene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Naphthalene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Phenanthrene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Pyrene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Phenols Trace in SVOC Soil Samples by GC-MS						
4-Chloro-3-methylphenol	mg/kg dry wt	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
2-Chlorophenol	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
2,4-Dichlorophenol	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2

Sample Type: Sediment						
Sample Name:		Site 1 Nottingham 22-Mar-2016 10:00 am	Site 2 Creamery 22-Mar-2016 12:00 pm	Site 3 Knights 22-Mar-2016 2:00 pm	Site 4 Halswell City Limits 21-Mar-2016 12:30 pm	Site 5 Haswell Wroots 21-Mar-2016 3:45 pm
Lab Number:		1557609.1	1557609.2	1557609.3	1557609.4	1557609.5
Phenols Trace in SVOC Soil Samples by GC-MS						
2,4-Dimethylphenol	mg/kg dry wt	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
3 & 4-Methylphenol (m- + p-cresol)	mg/kg dry wt	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
2-Methylphenol (o-Cresol)	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
2-Nitrophenol	mg/kg dry wt	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
Pentachlorophenol (PCP)	mg/kg dry wt	< 6	< 6	< 6	< 6	< 6
Phenol	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
2,4,5-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
2,4,6-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Plasticisers Trace in SVOC Soil Samples by GC-MS						
Bis(2-ethylhexyl)phthalate	mg/kg dry wt	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Butylbenzylphthalate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Di(2-ethylhexyl)adipate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Diethylphthalate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Dimethylphthalate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Di-n-butylphthalate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Di-n-octylphthalate	mg/kg dry wt	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS						
1,2-Dichlorobenzene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
1,3-Dichlorobenzene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
1,4-Dichlorobenzene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
Hexachlorobutadiene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
Hexachloroethane	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.14	< 0.10
1,2,4-Trichlorobenzene	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Other SVOC Trace in SVOC Soil Samples by GC-MS						
Benzyl alcohol	mg/kg dry wt	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Carbazole	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Dibenzofuran	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Isophorone	mg/kg dry wt	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10

Analyst's Comments

#1 Chrysene is higher than expected when compared to Benzo[a]anthracene. It is possible that Benzo(l)phenanthrene is present which co-elutes with Chrysene.

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-5
Dry Matter (Env)	Dried at 103°C for 4-22hr (removes 3-5% more water than air dry) , gravimetry. US EPA 3550. (Free water removed before analysis).	0.10 g/100g as rcvd	1-5
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-5
Total Recoverable Copper	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	2 mg/kg dry wt	1-5
Total Recoverable Lead	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	0.4 mg/kg dry wt	1-5
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-5

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Total Recoverable Zinc	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	4 mg/kg dry wt	1-5
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-5
7 Grain Sizes Profile*		-	1-5
Polycyclic Aromatic Hydrocarbons Trace in Soil	Sonication extraction, SPE cleanup, GC-MS SIM analysis US EPA 8270C. Tested on as received sample [KBIs:5784,4273,2695]	0.002 - 0.010 mg/kg dry wt	1-5
Semivolatile Organic Compounds Trace in Soil by GC-MS	Sonication extraction, GPC cleanup, GC-MS FS analysis. Tested on as received sample	0.10 - 6 mg/kg dry wt	1-5
7 Grain Sizes Profile			
Dry Matter	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-5
Fraction < 2 mm, >/= 1 mm*	Wet sieving using dispersant, 2.00 mm and 1.00 mm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5
Fraction < 1 mm, >/= 500 µm*	Wet sieving using dispersant, 1.00 mm and 500 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5
Fraction < 500 µm, >/= 250 µm*	Wet sieving using dispersant, 500 µm and 250 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5
Fraction < 250 µm, >/= 125 µm*	Wet sieving using dispersant, 250 µm and 125 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5
Fraction < 125 µm, >/= 63 µm*	Wet sieving using dispersant, 125 µm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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