Ōtūkaikino River Catchment Aquatic Ecology

Long-term monitoring of the Ōtūkaikino River catchment
Prepared for the Christchurch City Council

19 June 2017

Document Quality Assurance

Bibliographic reference for citation:
Boffa Miskell Limited 2017. *Ōtūkaikino River Catchment Aquatic Ecology: Long-term monitoring of the Ōtūkaikino River catchment*. Report prepared by Boffa Miskell Limited for the Christchurch City Council.

Prepared by:	Katie Noakes Graduate Ecologist Boffa Miskell Limited	
Reviewed by:	Tanya Blakely Ecologist / Associate Principal Boffa Miskell Limited	
Status: [FINAL]	Revision / version: [0]	Issue date: 19 June 2017

Template revision: 20150330 0000

File ref:
U:\2017\C17003_TBI_Otukaikino_Aquatic_Ecology_2017\Documents\C17003_005d_Otukaikino_Aquatic_Ecology_Draft_Report_20170619.docx

Cover photograph: Site 3: Kaikanui Creek; Boffa Miskell, 2017

Contents

Executive Summary

The Christchurch City Council (CCC) commissioned Boffa Miskell Limited to conduct an aquatic ecological survey of nine sites within the Ōtūkaikino River catchment. This survey forms part of the CCC's long-term monitoring of the Ōtūkaikino River and is a requirement of its Interim Global Stormwater Consent and the proposed Comprehensive Stormwater Network Discharge Consent.

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 to 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 nine sites located in the Ōtūkaikino River catchment in March 2017.

The basic water-quality parameters of pH, dissolved oxygen, conductivity and temperature were within ranges expected in spring-fed plains waterways during base-flow conditions. In-stream and riparian conditions, although variable among sites, were generally in good condition with high substrate indexes (indicating stream-bed substrates dominated by cobbles). Shading was present at most sites, and there was a diversity of in-stream habitat, with little channel modification at most sites. Macrophytes were present at all sites, however, total cover was low; and filamentous algae were rare. The majority of sites were below guidelines of Environment Canterbury's Land and Water Regional Plan and the Waimakariri River Regional Plan for 'spring-fed plains' waterways.

The contaminant concentrations in sediment collected from each site were generally low, and below the ANZECC guidelines, with the exception of zinc and copper in Site 3: Kaikanui Creek downstream of Clearwater Resort, and Site 7: Waimakariri River South Branch off Coutts Island Road, respectively, which exceeded the ISQG-low of the ANZECC (2000) sediment quality guidelines. Some contaminants, such as total organic carbon and total polycyclic aromatic hydrocarbons, were similar to levels found in surrounding urban catchments. Sites with elevated contaminant levels may be associated with areas of development within the catchment, but could also be from natural sources.

The macroinvertebrate communities were dominated by taxa typical of spring-fed waterways. While the pollution-sensitive or "clean-water" EPT taxa (i.e. mayflies, stoneflies, and caddisflies) dominated the macroinvertebrate community at most sites, this was largely due to a few caddis taxa and *Deleatidium* mayflies. Stoneflies were never found in 2017, but had been previously found at one site in 2012, and at three sites in 2008.

The fish communities were depauperate, with species richness generally around three to five fish species present at a site. Upland bullies and shortfin eels dominated the community composition, which was similar to the previous fish survey of 2011. The most notable difference between this study (2017) and 2011 (Aquatic Ecology 2013) was that longfin eels (an "at risk, declining" species) were more abundant in 2017, than 2011.

This ecological assessment indicated that the waterways within the Ōtūkaikino River catchment area were generally of good-excellent ecological health. Pollution-sensitive EPT taxa were present at all sites, and longfin eels were present at the majority of sites (8 of the 9 sites).

Although the Ōtūkaikino River catchment generally had "good" ecological health, some sites are lacking adequate riparian buffer zones. Enhancement of these riparian zones, and improvement

of in-stream habitat conditions, should be considered to maintain and enhance ecosystem health and protect these waterways from future degradation.

Background

The Ōtūkaikino River catchment is around 16 km^2 and located to the north-west of Christchurch City. Ōtūkaikino River is sourced from shallow groundwater from the near-by Waimakariri River. Its multiple tributaries flow through flat, predominantly rural, land until it joins the Waimakariri River main stem. Although draining predominantly rural land, there is increasing residential development in the outlying areas of Christchurch City and the Ōtūkaikino River catchment is changing from rural to urban land use.

Monitoring of the Ōtūkaikino River catchment is part of the Christchurch City Council's (CCC) long-term monitoring programme and is undertaken every 5 years. Monitoring is also required as part of the Council's Interim Global Stormwater Consent (IGSC) and the proposed Comprehensive Stormwater Network Discharge Consent (CSNDC). This study will be the third time this catchment has been monitored, with the previous three monitoring occasions undertaken in 2011 (fish community: Aquatic Ecology 2013), and 2008 and 2012 (habitat conditions and macroinvertebrate community: EOS 2008, 2012).

Scope

The CCC commissioned Boffa Miskell to conduct an aquatic ecology survey of nine sites within the Ōtūkaikino River catchment. This survey was designed to investigate the effects of stormwater on the aquatic ecology of the Ōtūkaikino River catchment 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 surface water quality outcomes and standards of Environment Canterbury's Land and Water Regional Plan (LWRP) and the Waimakariri River Regional Plan Water Quality Standards (WRRP); as well as the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) guidelines for sediment quality;
- Comparing trends over time by assessing the current conditions against the results of previous surveys (EOS Ecology 2008, 2012; Aquatic Ecology 2013);
- Discussing overall ecological health of the sites and identifying areas with high or low ecological health; and
- Recommending how to improve the ecological health, particularly where:
    - Water quality objectives have not been met; and
    - Any significant long-term trends have been observed.

Methods

Site locations

The CCC provided Boffa Miskell with northing and easting co-ordinates and location details for 9 sites (shown in Table 1) located in the Ōtūkaikino River catchment.

Table 1: Freshwater ecology survey sites within the Ōtūkaikino River catchment

Site number	Site name	Easting	Northing
1	Waimakariri River South Branch upstream of Dickeys Road	2479660	5752383
2	Waimakariri River South Branch at the Groynes dog park	2478558	5751288
3	Kaikanui Creek downstream of Clearwater Resort	2478147	5751998
4	Waimakariri River South Branch at Clearwater Resort	2476908	5750470
5	Otukaikino Creek at Clearwater Resort	2476908	5750470
6	Otukaikino Creek at Omaka Scout Camp	2474833	5751369
7	Waimakariri River South Branch off Coutts Island Road	2473541	5751286
8	Waimakariri River South Branch headwaters	2473541	5751286
9	Otukaikino Creek at McLeans Island Road	2472871	5748547

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 9 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 community were conducted between 15 and 17 March 2017. At each site, habitat and macroinvertebrates were assessed within a 20 m reach. Approximately 1 week later, the 21 and 22 March 2017, the fish community was assessed within a reach of at least 30 m (minimum 30 m and 30 m^2), which also included the habitat and macroinvertebrate reach.

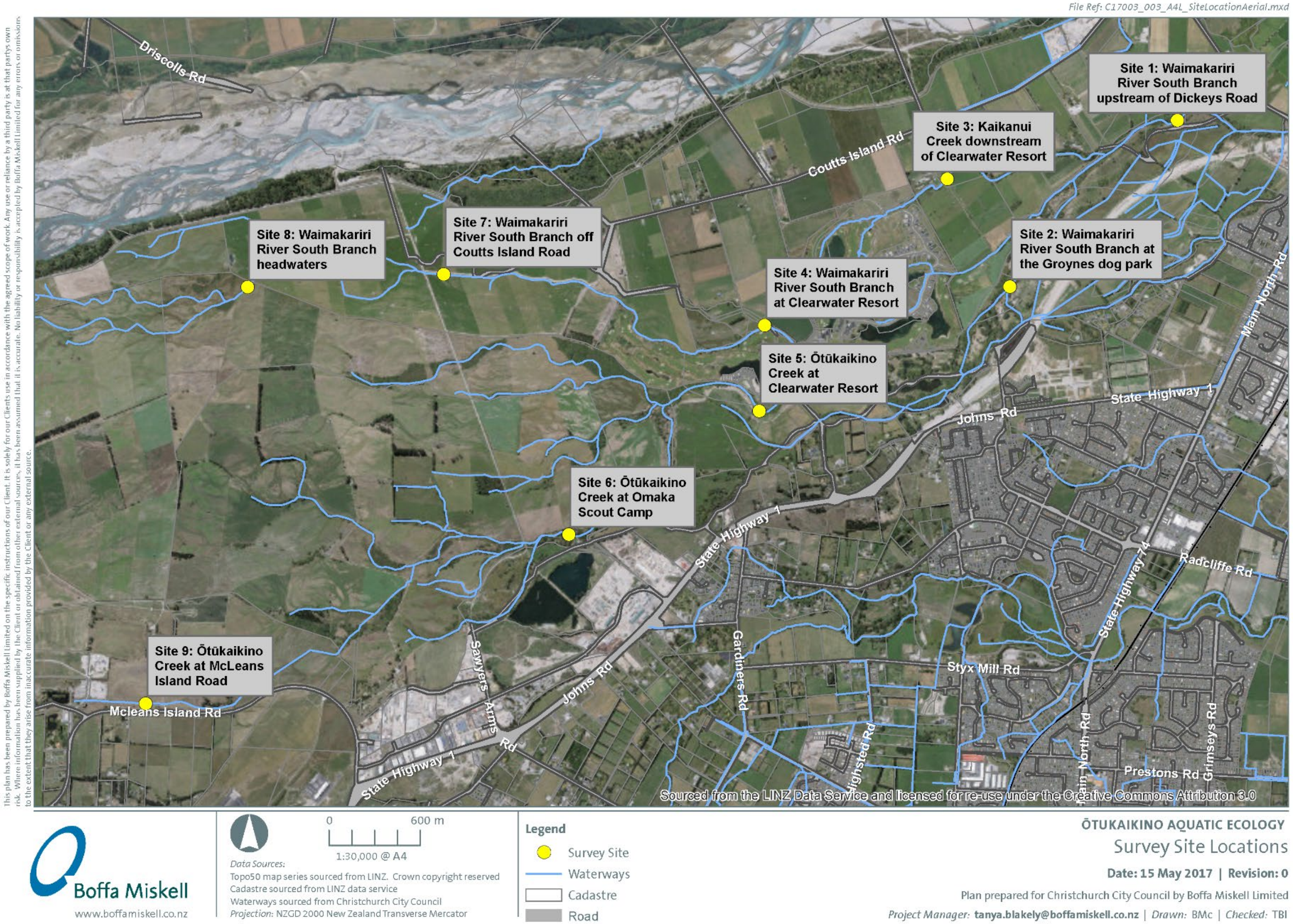


Figure 1. Locations of the nine sites in the Ōtūkaikino River catchment, surveyed in March 2017.

Habitat conditions

A variety of riparian and in-stream habitat parameters were recorded at each site (on 15-17 March 2017), 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 an EXO2 Sonde 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).

Velocity

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 nine 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). 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 nine survey sites in March 2017.

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 Biolive Invertebrate Identification Service 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[1] within the same reach (minimum of 30 m in length and 30 m^2 in area) where the macroinvertebrate community and habitat assessments were made one week earlier on 21 and 22 March.

The fish community at sites 2-9 were surveyed using electric-fishing techniques. At each site, 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). Each reach was divided into many subsections of approximately 2-3 m in length and the fish community surveyed using a single pass with a Kainga EFM 300 backpack mounted electric-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 21 and 22 March 2017.

Site 1 (Waimakariri South Branch, upstream of Dickeys Road) was too deep and, therefore, electric-fishing techniques were not safe, nor an appropriate method for sampling. 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 (21 March 2017) and left overnight. The following morning (22 March 2017), all fish captured were identified and measured (fork length, mm) before being returned alive to the stream.

---

[1] 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.

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 conditions over time

As part of the CCC's long term monitoring of Christchurch's waterways, EOS Ecology (EOS Ecology 2008, 2012) also conducted a survey of the Ōtūkaikino River catchment in March 2008 and 2012. The same sites were surveyed in all three surveys. This allowed a comparison to be made between some habitat conditions in 2008, 2012 (EOS Ecology 2012) and 2017 (this study)[2].

For those parameters where field methods were generally comparable across the two surveys, two-way analyses of variance (ANOVA) were used to test for differences over time. Parameters tested included, water depth, sediment depth, velocity, and substrate index. EOS (2012) took 12 measures of each of these parameters at each transect. Whereas, in this study (2017) 5 measures of water depth, sediment depth, and substrate index were taken at each transect, while velocity was measured once at each transect.

In order to deal with the differences in sampling effort between these two studies, analyses were conducted on average values for each transect, giving three measures of each response variable for each site, in 2012 and 2017.

Where necessary, response variables were log transformed to meet assumptions of normality and homogeneity of variances. ANOVAs were performed in R version 3.3.1 (The R Foundation for Statistical Computing 2013).

[2] Note, only visual and qualitative comparisons to the findings of EOS Ecology (2008) were made; statistical analyses were limited to 2012 and 2017 comparisons.

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 18 PAHs analysed, which include 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 9 (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 9 was the worst site overall (based on sediment contaminant concentrations).

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 abundance** – 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 abundance (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 9 (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 9 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 2008, 2012 (EOS Ecology 2008, 2012) and 2017 (this study); statistical analyses were not conducted as there was no replication within sites. It is important to note that the area sampled in 2008 and 2012 greater than that sampled in 2017[3].

A non-metric multidimensional scaling (or NMDS) ordination[4], with 1000 random permutations, of abundance data was used to determine if the macroinvertebrate community found was similar between 2012 (EOS Ecology 2012) and 2017 (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 2012

[3] EOS Ecology (2008, 2012) collected three replicate kick-net samples from an area of 0.3 x 1.5 m per site; whereas a single kick-net sample from an area of 0.3 x 2.0 m was collected from each site in the 2017 survey. Thus, EOS Ecology sampled approximately three times more habitat at each site in 2008 and 2012, compared to 2017. However, the three kick-net samples from EOS Ecology surveys were averaged, giving a comparable area surveyed across years. It is noteworthy, that because more area was surveyed by EOS Ecology (2008, 2012), there was a greater chance of detecting rare taxa (i.e. based on the ecological principle, species-area curve).

[4] 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).

and 2017. 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 2012 and 2017. 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[5].

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[6] 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 (2017) with the findings from previous surveys conducted in 2011 (Aquatic Ecology 2013). Note, survey locations are not entirely overlapping, and the comparisons in fish fauna overtime are from approximately similar site locations[7].

---

[5] 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.

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

[7] Site 4: Waimakariri River South Branch at Clearwater Resort matched closely with Aquatic Ecology's (2013) site 8 (lower north boundary stream); Site 5: Ōtūkaikino Creek at Clearwater Resort matched closely with Aquatic Ecology's (2013) site 10 (lower Ōtūkaikino mainstem); Site 6: Ōtūkaikino Creek at Omaka Scout Camp matched with Aquatic Ecology's (2013) site 16 (upper Ōtūkaikino mainstem); and Site 7: Waimakariri River South Branch off Coutts Island Road matched closely with Aquatic Ecology's (2013) site 6 (upper north boundary stream).

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 nine sites, ranging between 52 µS / cm and 68 µS / cm (Figure 2). The highest recorded conductivity was in Site 3: Kaikanui at Clearwater. However, the difference between the conductivity recorded in Kaikanui Stream and that of other sites was negligible.

Moreover, the conductivities were significantly lower than those recorded in many urban systems such as the Halswell River (Boffa Miskell 2013) and Avon River (Boffa mIskell 2013) catchments.

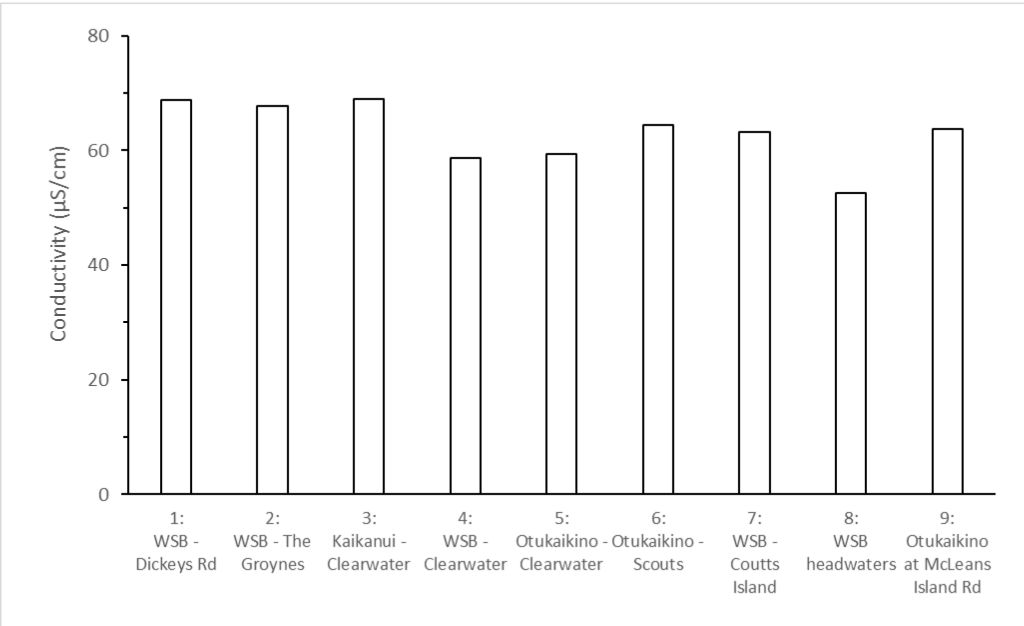


Figure 2: Specific conductivity measured, on one occasion, at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017.

pH

pH was similar across sites, with circum-neutral pH recorded in all nine 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.

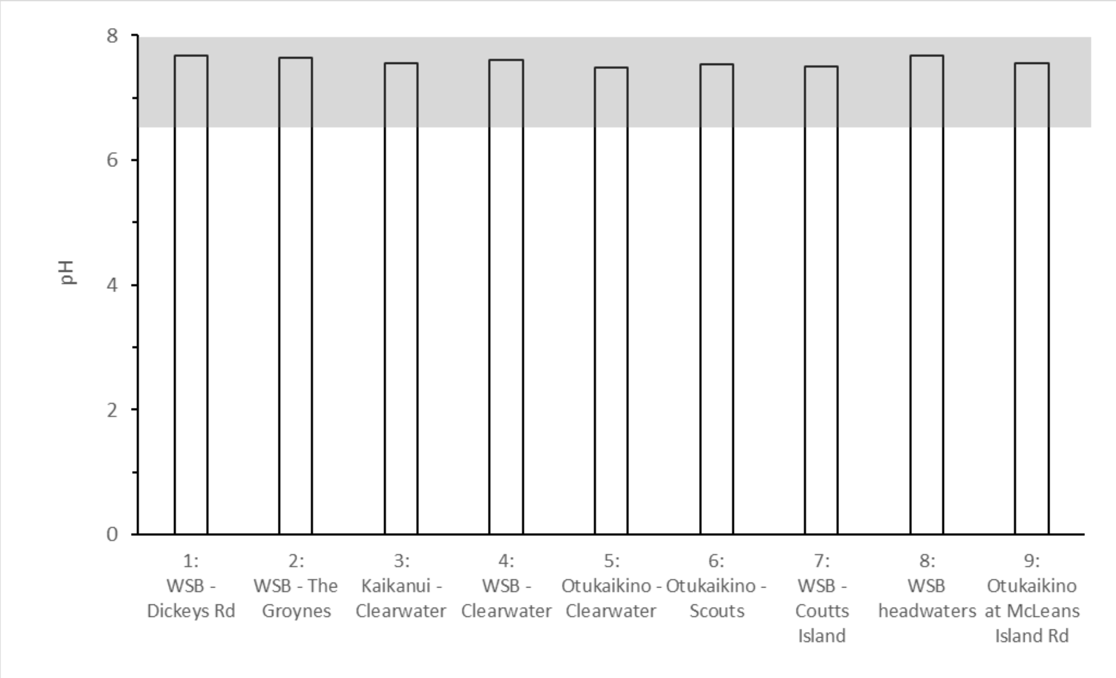


Figure 3: pH measured, on one occasion, at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017. The grey shaded area indicates Canterbury's Land and Water Regional Plan (LWRP) recommended water quality standard for receiving waters of pH between 6.5 and 8.5.

Dissolved oxygen

Dissolved oxygen (DO), overall was high at all sites, with greater than 100% saturation DO recorded at Site 7: Waimakariri at Coutts Island Rd and Site 9: Ōtūkaikino at McLeans Island Road (Figure 4). Dissolved oxygen was measured only once during the daytime, and at different times of the day across the five sites. All sites met the WRRP water quality standards which state DO shall exceed 80%, with the lowest DO recorded was 83% at sites 5 and 8 DO can vary diurnally and seasonally, and macrophyte and algal abundances at a site can greatly influence DO concentrations.

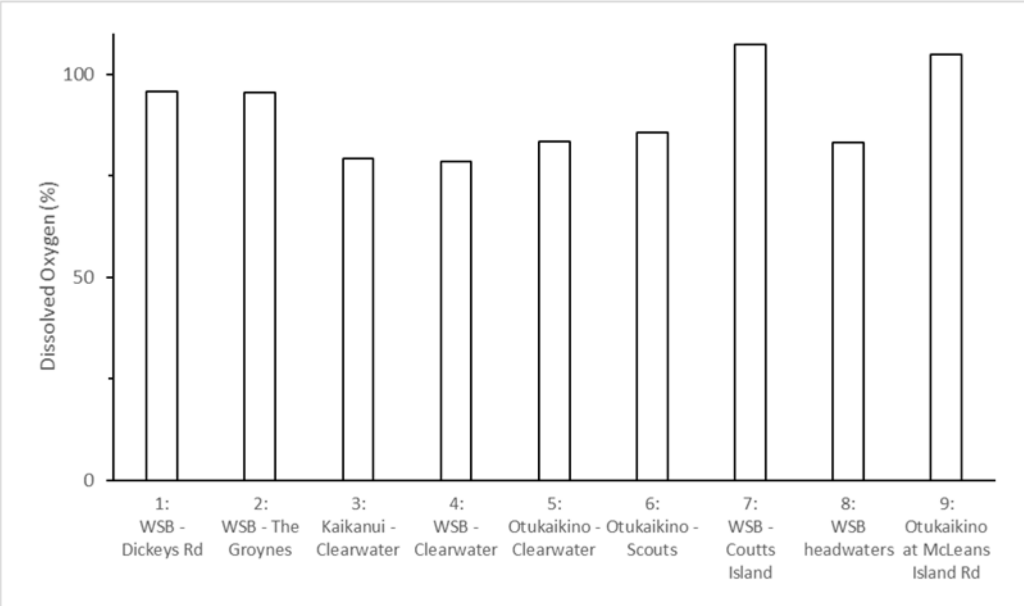


Figure 4: Dissolved Oxygen (%) measured, on one occasion, at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017.

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) and the WRRP maximum of 25°C... The coolest water temperature of 12.7°C was recorded in Site 3: Kaikanui at Clearwater, while Site 7: Waimakariri at Coutts Island Road had the highest water temperature (17.6°C). 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.

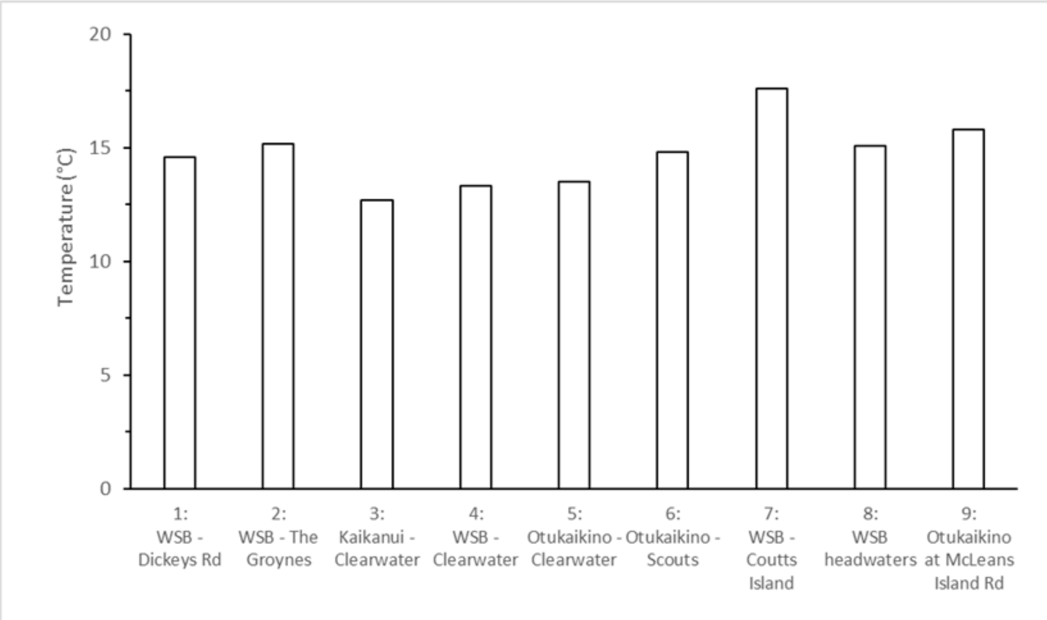


Figure 5: Temperature (°C) measured, on one occasion, at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017.

Velocity

Water velocity was highly variable amongst sites, with the fastest velocity recorded in Site 9: Ōtūkaikino Creek at McLeans Island Road (although velocity was highly variable as shown by the standard error bars in (Figure 6), while Site 8: Waimakariri South Branch had the slowest velocity (Figure 6).

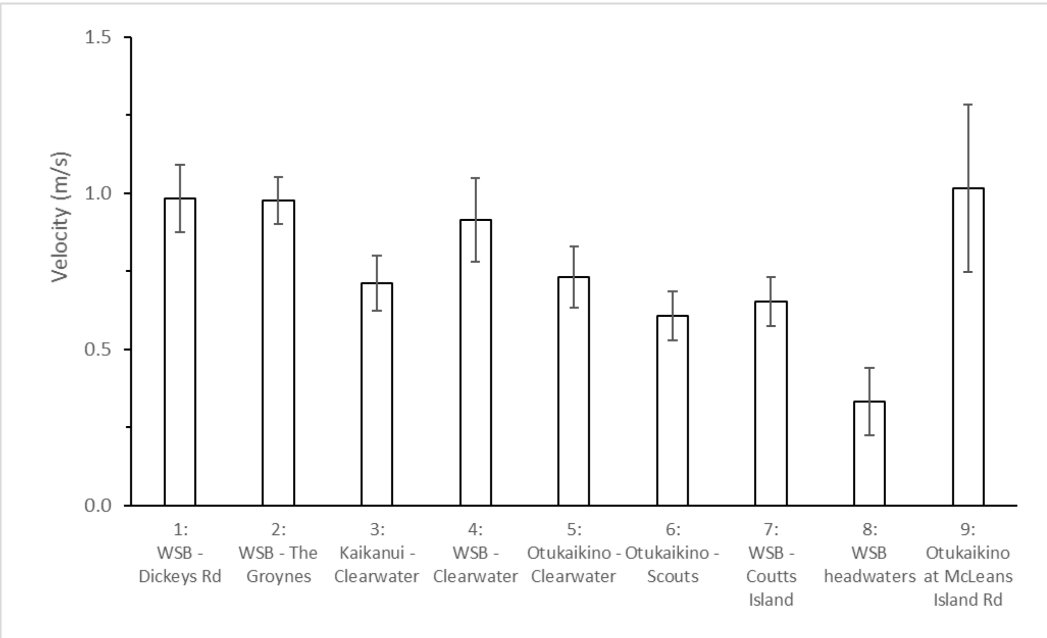


Figure 6. Mean (±1SE, n = 3) velocity (m / s) measured once at each of three transects at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017.

Velocity was significantly different among sites (ANOVA: $F_{8,37}$= 5.67; P < 0.001), and different between years (ANOVA: $F_{1, 20}$ = 54.05; P < 0.001) (Figure 7). Velocity was generally slower in 2012, than in 2017, with the exception of Site 3: Kaikanui Creek downstream of Clearwater Resort and Site 6: Ōtūkaikino Creek at Omaka Scout Camp where velocities were not statistically significantly different (Figure 6).

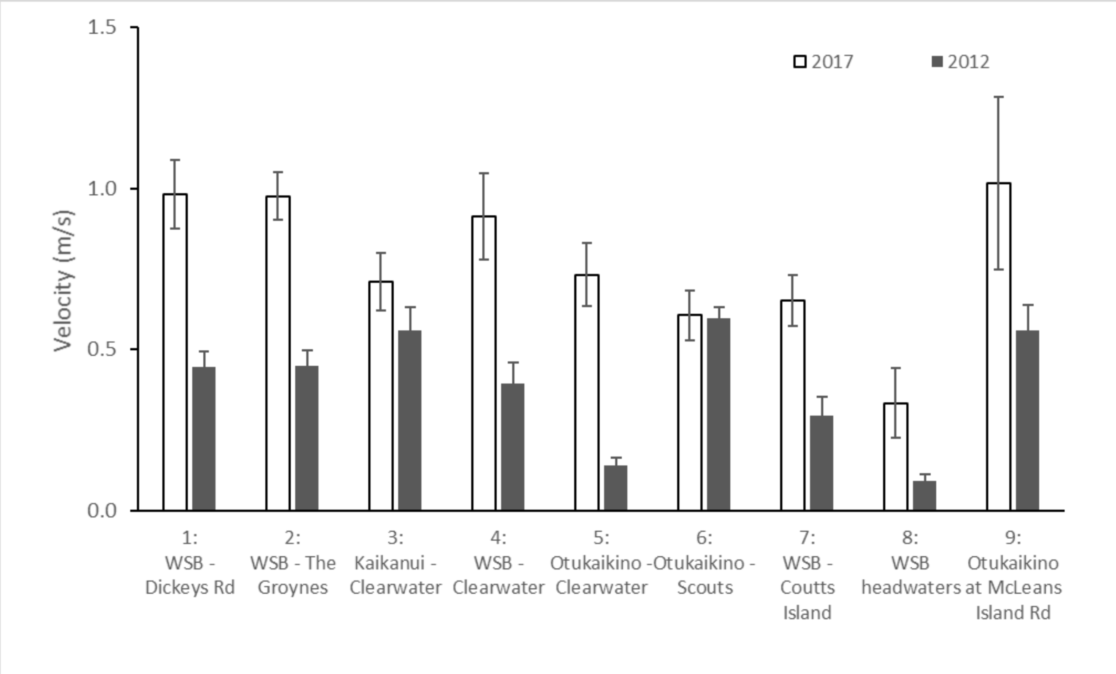


Figure 7: Mean (±1SE) velocity (m / s) measured at each of three transects at the nine sites surveyed within the Ōtūkaikino River catchment in March 2012 (grey bars; EOS Ecology 2012) and March 2017 (white bars; this study).

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 nine sites surveyed between 15 and 17 March 2017. 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: Waimakariri River South Branch upstream of Dickeys Road	TLB: Reserve / park TRB: Reserve / park	TLB: Earth TRB: Earth	TLB: 80% TRB: 35%	TLB: 27 cm TRB: 27 cm	TLB: 465 cm TRB: 290 cm	TLB: 97% TRB: 87%	10: 0: 40: 50: 0
Site 2: Waimakariri River South Branch at the Groynes dog park	TLB: Reserve / park TRB: Reserve / park	TLB: Earth TRB: Earth	TLB: 27% TRB: 17%	TLB: 25 cm TRB: 13 cm	TLB: 235 cm TRB: 317 cm	TLB: 93% TRB: 97%	20: 0: 0: 80: 0
Site 3: Kaikanui Creek downstream of Clearwater Resort	TLB: Rural, farming TRB: Rural, farming	TLB: Earth and concrete TRB: Earth	TLB: 3% TRB: 2%	TLB: 10 cm TRB: 0 cm	TLB: 23 cm TRB: 18 cm	TLB: 82% TRB: 80%	0: 5: 0: 5: 90
Site 4: Waimakariri River South Branch at Clearwater Resort	TLB: Retired grass TRB: Golf Course	TLB: Earth TRB: Earth	TLB: 40% TRB: 30%	TLB: 7 cm TRB: 13 cm	TLB: 18 cm TRB: 70 cm	TLB: 93% TRB: 80%	8: 2: 0: 90: 0
Site 5: Ōtūkaikino Creek at Clearwater Resort	TLB: Retired grass TRB: Retired grass	TLB: Earth TRB: Earth	TLB: 37% TRB: 47%	TLB: 10 cm TRB: 4 cm	TLB: 30 cm TRB: 10 cm	TLB: 97% TRB: 92%	20: 0: 0: 80: 0
Site 6: Ōtūkaikino Creek at Omaka Scout Camp	TLB: Lawn TRB: Lawn	TLB: Earth TRB: Earth	TLB: 40% TRB: 12%	TLB: 5 cm TRB: 0 cm	TLB: 20 cm TRB: 2 cm	TLB: 27% TRB: 83%	5: 0: 0: 85: 10
Site 7: Waimakariri River South Branch off Coutts Island Road	TLB: Rural, dairy farm TRB: Rural, dairy farm	TLB: Earth TRB: Earth	TLB: 3% TRB: 2%	TLB: 0 cm TRB: 4 cm	TLB: 10 cm TRB: 10 cm	TLB: 100% TRB: 100%	40: 0: 0: 60: 0
Site 8: Waimakariri River South Branch headwaters	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth	TLB: 27% TRB: 3%	TLB: 3 cm TRB: 3 cm	TLB: 73 cm TRB: 8 cm	TLB: 90% TRB: 97%	20: 0: 20: 50: 10
Site 9: Ōtūkaikino Creek at McLeans Island Road	TLB: Rural, farming TRB: Rural, farming	TLB: Earth TRB: Earth	TLB: 2% TRB: 6%	TLB: 0 cm TRB: 0 cm	TLB: 0 cm TRB: 38 cm	TLB: 67% TRB: 38%	10: 0: 0: 60: 30

General site descriptions

Site 1: Waimakariri River South Branch upstream of Dickeys Road

Site 1 was located at the downstream extent of the Groynes dog park, the most downstream sampling location within this catchment. Here the stream was, on average, 12 m wide, 0.70 m deep and fast flowing with some deeper pools along the reach. The velocity measurement on the day of sampling was 0.98 m / s. The mid channel was fast flowing with a cobble base. The channel margins had deeper pools and slower flowing water. On average, there was 4.5 m of overhanging willows on the true left bank and areas of macrophyte beds on the true right side.

The mid channel stream bed was dominated by pebbles and gravels, however, the margins and edges were covered in depositional silt, particularly in the deeper pools, giving an average Substrate Index of 4.17. Macrophytes were common at the site, with beds of submerged Canadian pondweed (*Elodea canadensis*) and curly pondweed (*Potamogeton crispus*). There was considerable canopy cover at this site (80%) with a great deal of overhanging vegetation, predominantly willows (Table 4). There was very low algal cover at the site with filamentous algae covering only 1% of the total site area.

Photo 1. Site 1: Waimakariri River South Branch upstream of Dickeys Road, looking upstream (top left); downstream (top right); and with a fyke net set during fishing survey (bottom).

Site 2: Waimakariri River South Branch at the Groynes dog park

Site 2 was located within the Groynes dog park, 1.6 km upstream of Site 1. Here, the Waimakariri River South Branch was largely run habitat with an average wetted width of 12.5 m and an average depth of 0.5 m. The velocity on the day of sampling was 0.07 m / s. The river channel was largely dominated by cobble substrate giving an average Substrate Index of 4.8.

Macrophytes were common at the site, particularly within the margins, with submerged species such as curly pondweed (*Potamogeton crispus*), Canadian pondweed (*Elodea canadensis*) and water buttercup (*Ranunculus trichophyllus*) dominating. Emergent macrophytes included large beds of willow weed (*Persicaria hydropiper*). The riparian vegetation was largely made up of exotic species such as willow (Salix spp.) and blackberry (*Rubus fruticosus*) with up to 5 m of overhanging vegetation on the true left bank (Table 4). The taller willows at this site provided some shading to the stream, with no filamentous algae being found.

Photo 2. Site 2: Waimakariri River South Branch at the Groynes dog park, looking upstream (left); and downstream (right).

Site 3: Kaikanui Creek downstream of Clearwater Resort

Site 3 was located in the Kaikanui Creek, 1.1 km upstream of the confluence with Waimakariri River South Branch. The creek was on average 5.7 m wide with an average water depth of 0.22 m and was largely riffle habitat. A small spring-fed tributary joined on the true right side, 12 m upstream of the most downstream transect. On the day of sampling, the velocity was 0.7 m / s. The channel was dominated by coarse, cobble substrate, giving a Substrate Index of 4.6.

Macrophytes were less common, than at Sites 1 & 2, and limited to the channel margins with the floating macrophyte duckweed (*Lemna minor*) being the dominant species. Filamentous algae were not recorded at this site, with the cobble substrate being covered in thin algae and bryophyte mats.

The riparian margin was dominated by short grasses, providing little shade and habitat for fish and other aquatic fauna (Table 4). The sampling location was on a farm and old concrete troughs and blocks were scattered along the stream banks, providing some undercut habitat for fish species, such as eels.

It was noted, from the previous survey's photos that willows once dominated the riparian zone, however, these have been removed and the riparian margins are now grassed (reduced canopy cover and in-stream shading).

Photo 3. Site 3: Kaikanui Creek downstream of Clearwater Resort, looking upstream (left); and downstream (right).

Site 4: Waimakariri River South Branch at Clearwater Resort

Site 4 was located within the Clearwater Resort on the edge of the golf course, 440 m upstream of the confluence with Ōtūkaikino Creek. Here, the river was largely run habitat with an average width of 4.3 m and depth of 0.28 m. The velocity on the day of sampling was 0.9 m / s. The channel was relatively consistent in width, however, immediately downstream of the survey reach the river widened considerably forming a large and deep (approximately 1 m) pool. The substrate was dominated by smaller cobbles in the mid channel and sand towards the margins giving a Substrate Index of 4.7.

Macrophytes were only found at the downstream end of the survey reach, where watercress (*Nasturtium officinale*) and duckweed (*Lemna minor*) were found. The upstream part of the survey reach had exposed willow roots mats on the wetted edges, particularly on the true left bank. The riparian zone was dominated by exotic vegetation willow (*Salix* spp.) and blackberry (*Rubus fruticosus*), which provided some shade and, on average, 44 cm of overhanging vegetation (Table 4). Overall, there was very little algae recorded at this site with only a small portion of the substrate being covered in thin film.

Photo 4. Site 4: Waimakariri River South Branch at Clearwater Resort, looking upstream (left); and downstream (right).

Site 5: Ōtūkaikino Creek at Clearwater Resort

Site 5 was located in Ōtūkaikino Creek, 0.5 m upstream of an access way culvert and 570 m upstream of the confluence with Waimakariri River South Branch. At this site, Ōtūkaikino Creek had an average width of 6.4 m and an average depth of 0.52 m. Velocity on the day of sampling was 0.73 m / s. The survey reach was mostly fast flowing run habitat, particularly at the upstream end of the reach where the stream narrowed into a smaller channel.

The margins were thick with macrophytes and overhanging vegetation where water was still. The mid channel was dominated by coarser substrates, however, the margins were covered in silt substrate, underneath the macrophytes, which gave an overall Substrate Index of 4.3.

Macrophytes were common at this site and covered the margins as well as areas within the middle of the channel. The downstream extent of the reach was dominated by emergent macrophytes of watercress (*Nasturtium officinale*) and monkey musk (*Mimulus guttatus*), whereas the upstream extent was dominated by submerged macrophytes, including Canadian pondweed (*Elodea canadensis*). The upper extent of the reach also had larger willows in the riparian zone, which provided high shade cover (42%) and extended into the river channel in the mid-section (Table 4).


Photo 5. Site 5: Otukaikino Creek at Clearwater Resort, looking upstream (left); and downstream (right).

Site 6: Ōtūkaikino Creek at Omaka Scout Camp

Site 6 was located in the Ōtūkaikino Creek at the Omaka Scout Camp grounds. Here, Ōtūkaikino Creek was relatively wide and shallow across the entire survey reach with an average depth of 0.13 m and width of 5.5 m. The velocity on the day of sampling was 0.6 m / s. The majority of the reach was run habitat with cobble substrate, giving a Substrate Index of 5.1.

The riparian zone was predominantly lawn with a few larger exotic trees on the true left bank, which provided some shade to the channel. There was very little macrophyte cover in the creek with only small patches of duckweed (*Lemna minor*) and Canadian pondweed (*Elodea canadensis*) found on the margins. Both short and long filamentous algae were present, covering 18% of the creek bed. The true right bank of the creek, at the downstream extent of the reach, was stabilised by concrete blocks (Table 4).

Photo 6. Site 6: Ōtūkaikino Creek at Omaka Scout Camp, looking upstream (left); and downstream (right).

Site 7: Waimakariri River South Branch off Coutts Island Road

Site 7 was located in the Waimakariri River South Branch, off Coutts Island Road, and was within a dairy farm. The site here was on average 3.7 m wide and 0.32 m deep. On the day of sampling the velocity was 0.6 m / s.

The flow habitat was run in the mid channel and still water closer to the margins. Cobble substrate dominated the bed, giving a Substrate Index of 4.4.

The margins had thick cover of the emergent macrophyte monkey musk (*Mimulus guttatus*) with patches of duckweed (*Lemna minor*) in between, which provided some cover to the stream. The riparian vegetation consisted of rank grasses and was continuous along the reach. Algal cover was low, despite the site being open with very little shade (Table 4).

Photo 7. Site 7: Waimakariri River South Branch off Coutts Island Road, looking upstream (left); and downstream (right)

Site 8: Waimakariri River South Branch headwaters

Site 8 was located in the upper headwaters of the Waimakariri River South Branch. Here, the river was relatively shallow and narrow, with an average depth of 0.16 m and average width of 2.9 m. The survey reach included flow habitats of run, pool and still waters. The velocity on the day of sampling was 0.1 m / s. The bed was dominated by cobbles, intermixed with pebbles and gravels and had a Substrate Index of 4.1.

Macrophytes were thick and dense along the majority of the reach with monkey musk (*Mimulus guttatus*) dominating. The site was along a paddock edge with the true right side being pasture grasses and the true left riparian zone being dominated by willows and grasses. The willows encroached into the stream along the majority of the reach, resulting in areas of backwater between the overhanging willows. The riparian conditions were markedly different in 2017, compared to 2012 (EOS Ecology 2012; see photos below).

Photo 8. Site 8: Waimakariri River South Branch headwaters, looking upstream (top left); and looking downstream (top right) in 2017; and looking upstream in 2008 (bottom left) and 2012 (bottom right). Bottom photos are taken from, EOS Ecology (2012).

Site 9: Ōtūkaikino Creek at McLeans Island Road

Site 9 was located in the upper reaches of Ōtūkaikino Creek. Here the channel was narrow, relative to the other sites surveyed, with an average width of 2.5 m. The average depth was 0.25 m. The velocity on the day of sampling was 1.01 m / s. The substrate was dominated by cobbles, with a Substrate Index of 5.9.

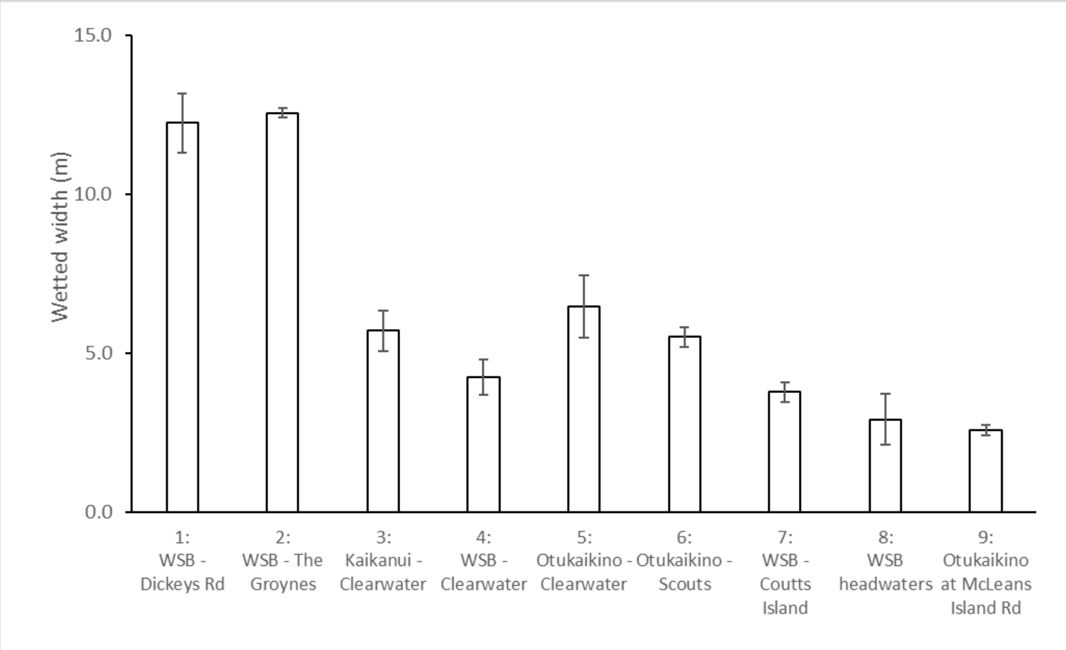
The macrophytes at this site were limited to the margins where watercress (*Nasturtium officinale*) and duckweed (*Lemna minor*) were common. The riparian zone was dominated by rank grasses, which provided no shading to the creek. Filamentous algae were absent, however, mats of thick algae were common on the larger cobbles. This site had no bank undercuts or overhanging vegetation, however, there was no fine sediment observed at this site and the interstitial spaces between the large cobbles provided habitat for aquatic fauna.

Photo 9. Site 9: Ōtūkaikino Creek at McLeans Island Road, looking upstream (left); and downstream (right).

Wetted width and water depth

Wetted width was greatest in Sites 1 and 2 (the two downstream most sites in the Waimakariri River South Branch) and narrowest in sites further up the catchment (Sites 3-9) (Figure 8).

Similarly, water depth was greatest in the wider downstream sites (Sites 1 & 2), but was variable for the sites in the upper catchment (Figure 8).



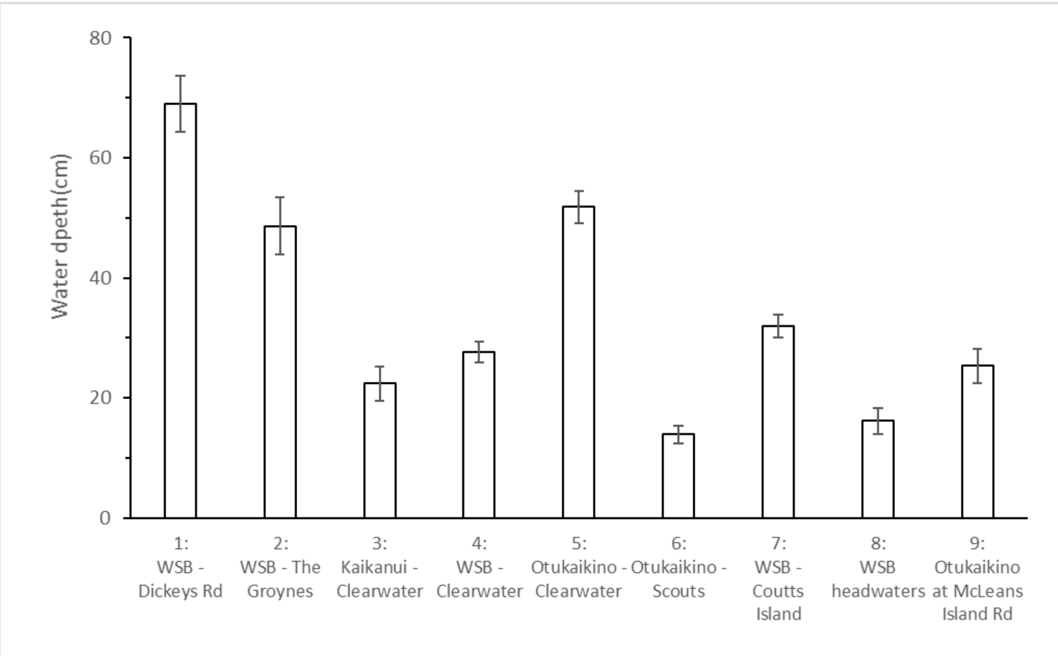


Figure 8: Mean (±1SE, n = 3) wetted width (m) (top) and water depth (cm) (bottom) measured once at each of three transects at the nine sites surveyed within the Otukaikino River catchment in March 2017.

Water depth was significantly different among sites (ANOVA: $F_{8,37} = 34.21$; $P < 0.001$), and significantly different between years (ANOVA: $F_{1, 20} = 20.72$; $P < 0.001$) (Figure 9).

Water depth was generally deeper in 2017, than in 2012, with the exception of sites 3, 5 and 6, which had very similar depths recorded in 2012 and 2017.

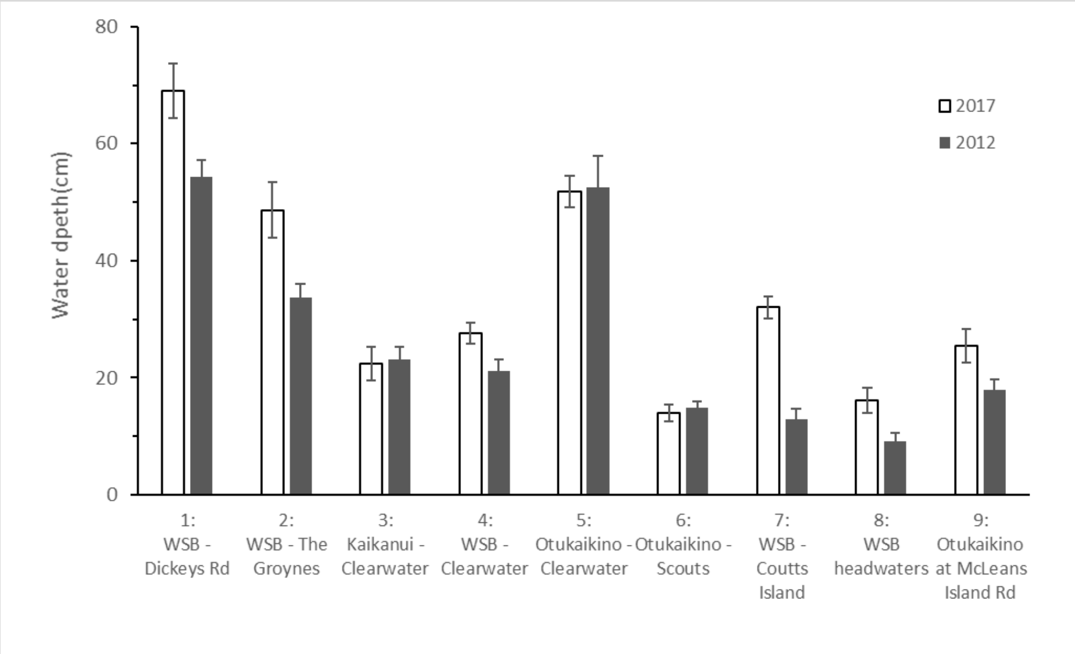


Figure 9: Mean (±1SE) water depth (cm) measured at each of three transects at the nine sites surveyed within the Otukaikino River catchment in March 2017 (white bars) and March 2012 (grey bars, EOS Ecology 2012).

Substrate index

The substrate index (SI), calculated from five replicate measures of percent substrate composition taken along each of the three transects at each site, generally ranged between 4.1 and 5.9. Site 9: Ōtūkaikino Creek at McLeans Island Road had the greatest SI of 5.9, indicating coarser substrates dominated by large cobbles, rather than smaller substrates (gravels and pebbles) that were found at the other sites.

Site 8: Waimakariri River South Branch headwaters had the lowest SI of 4.1, indicating the substrate was dominated by smaller cobbles and pebbles (Figure 10).

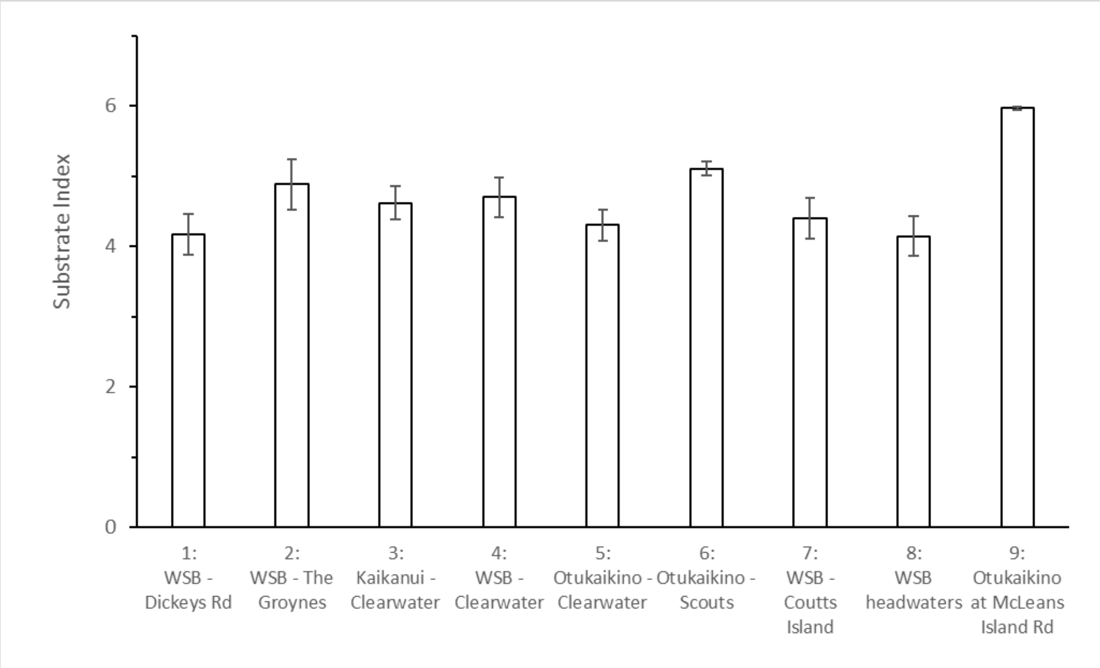


Figure 10: Mean (±1SE) substrate index calculated from substrate composition measures recorded at five locations along each of three transects at the five sites surveyed within the Otukaikinol River catchment and within the SWSMP in March 2016.

Substrate indexes were different between years (ANOVA: $F_{4, 20} = 20.38$; $P < 0.001$), and different between sites (ANOVA: $F_{4, 20} = 5.15$; $P < 0.001$) (Figure 11). All sites were estimated to have coarser substrate in 2017, than that measured by EOS Ecology in 2012[8].

[8] The Substrate Index was calculated using slightly different methods in 2012 versus 2017. EOS Ecology (2012) 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 (2017) 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.

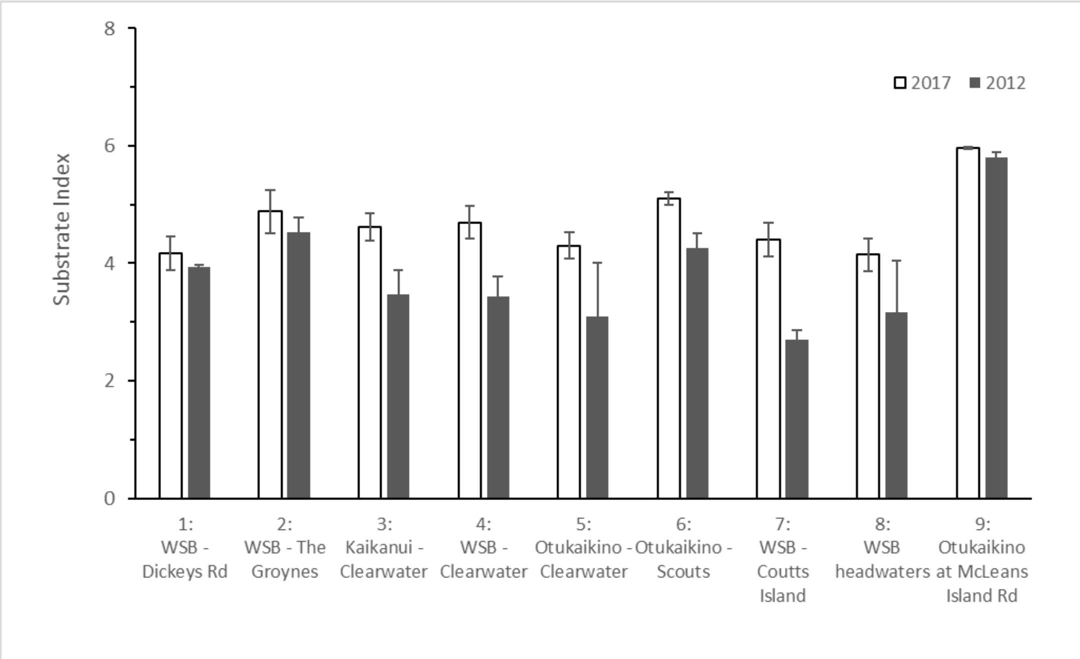


Figure 11: Mean (±1SE) Substrate Index measured once at each of three transects at the five sites surveyed within the Ōtūkaikino River catchment in March 2017 (white bars; this study) and March 2012 (grey bars; EOS Ecology 2012).

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 variable between all sites.

Fine sediments (<2 mm diameter) were present at most sites. The majority of sites had 10% (or less) cover (Sites 2, 3, 4, 6, 7, and 9). Site 1: Waimakariri River South Branch upstream of Dickeys Road, which included large, still pools where fine sediments had accumulated, had the highest fine sediment cover at 45%. Sites 8 and 5 had 40% and 20% fine sediment cover, respectively. Sites (1 and 8) exceeded LWRP standards of maximum of 20% fine sediment cover.

The cover of fine sediment at all sites surveyed was also reflected in the estimated embeddedness scores, as discussed below.

Embeddedness ranged between 1.3% and 50%. Site 8: Waimakariri River South Branch headwaters had the highest embeddedness across all sites with 50% recorded, while just 1.3% was recorded at Site 9: Otukaikino Creek at McLeans Island Road (Figure 12). The sites with the lowest embeddedness estimates also had the highest SI scores, which is unsurprising given that a low SI indicates bed substrates dominated by fine particles, and these particles are what embed (surround) coarser substrates.

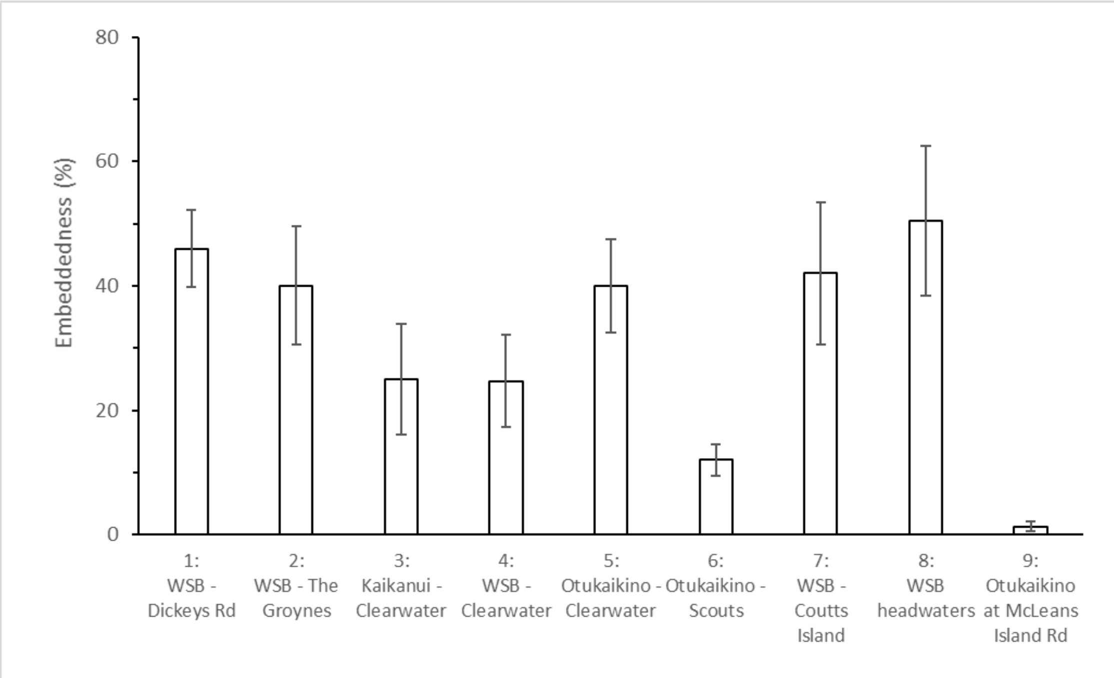


Figure 12: Mean (±1SE) percent embeddedness recorded at five locations along each of three transects at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017.

Soft sediment depth

Soft sediment depth across all sites was overall very low. The site with the greatest soft sediment depth was Site 8: Waimakariri River South Branch headwaters which had an average of 9.2 cm. The majority of the sample sites had between 1 and 3 cm of soft sediment depth, with Sites 4 and 5 having less than 1 cm cover. Site 9: Otukaikino Creek at McLeans Island Road having no soft sediment cover across the entire survey reach (Figure 13). The soft sediment measures were comparative to the embeddedness estimates at each of the sites; Site 8 had the highest embeddedness estimate and also the deepest sediment depth, whereas Site 9 had the lowest embeddedness estimate, and very little fine sediment found at the site.

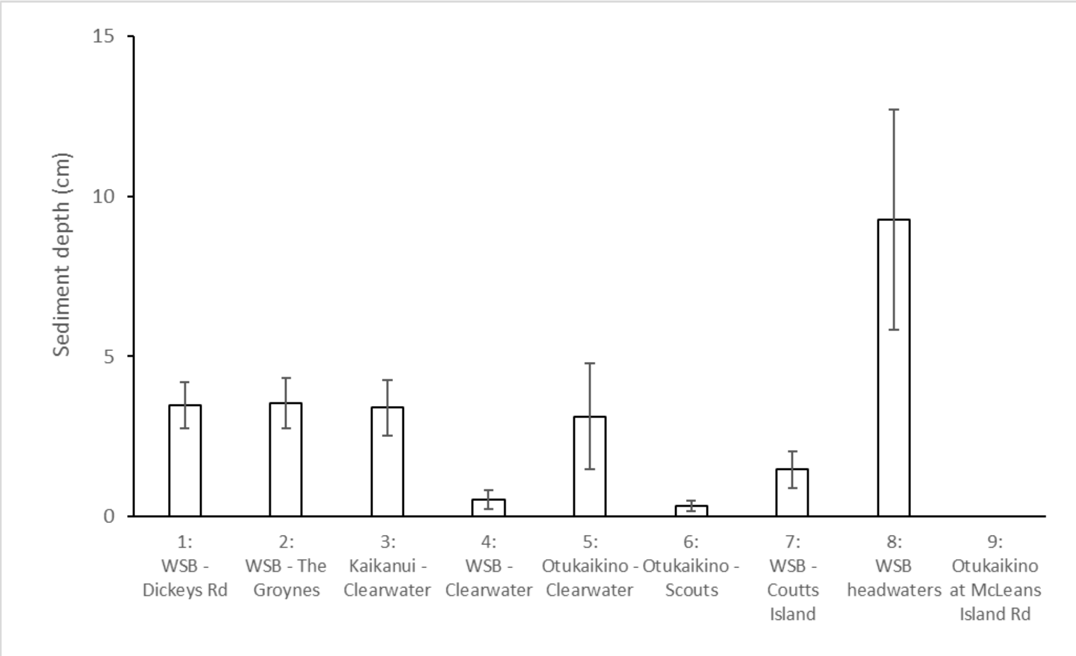


Figure 13: Mean (±1SE) soft sediment depth recorded at five locations along each of three transects at the nine sites surveyed within the Otukaikino River catchment in March 2017.

Soft sediment depth was slightly different between sites and (ANOVA: $F_{8,37} = 6.9$; $P < 0.001$), and different between years (ANOVA: $F_{1, 20} = 7.1$; $P = 0.011$). Overall, more fine sediment was recorded in most sites in 2012, than in 2017 (Figure 14). Site 7: Waimakariri River South Branch off Coutts Island Road showed the greatest change in soft sediment depth between 2012 and 2017.

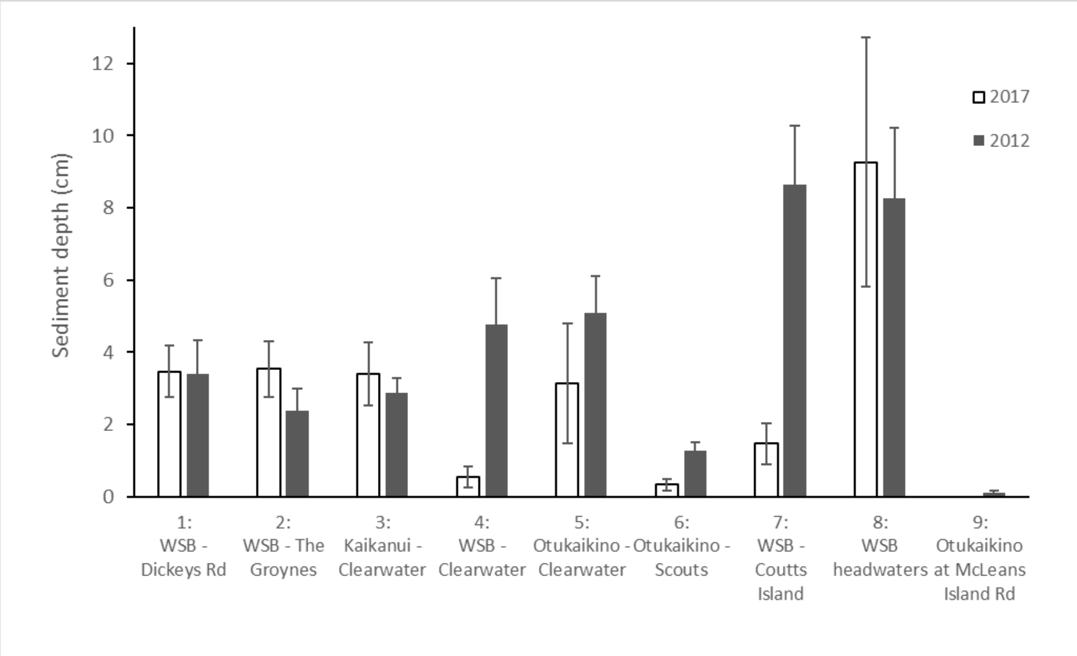


Figure 14: Mean (±1SE) depth of soft sediment covering the stream bed measured at each of three transects at the nine sites surveyed within the Otukaikino River catchment in March 2017 (white bars: this study); and in March 2012 (grey bars; EOS Ecology 2012).

Macrophytes

The percentage that emergent macrophytes covered the stream bed was relatively low across all sites, except for Site 7: Waimakariri River South Branch off Coutts Island Road and Site 8: Waimakariri River South Branch headwaters, which both exceeded the LWRP guideline for spring-fed plains waterways (maximum cover of emergent macrophytes - 30%) (Figure 15).

Macrophyte cover was lowest at Site 6: Ōtūkaikino Creek at Omaka Scout Camp, presumably due to coarse substrates (i.e. less suitable substrates for macrophyte roots to grow within) and relatively high canopy cover at this site.. Site 4: Waimakariri River South Branch at Clearwater Resort also had low macrophyte cover, which was largely due to shading of the channel provided by the extensive canopy cover.

None of the sites exceeded the total macrophyte cover guidelines of the LWRP for spring-fed plains waterways (maximum cover of 50%). The two sites, Sites 7 & 8, that exceeded the 30% threshold for emergent macrophytes had little, or no, riparian margin or canopy cover and the margins were thick with monkey musk (*Mimulus guttatus*) with scattered duckweed (*Lemna minor*), or watercress (*Nasturtium officinale)*. This highlights the importance of riparian vegetation, and especially tall trees, to provide shading, which contributes to managing macrophyte and algae growth.

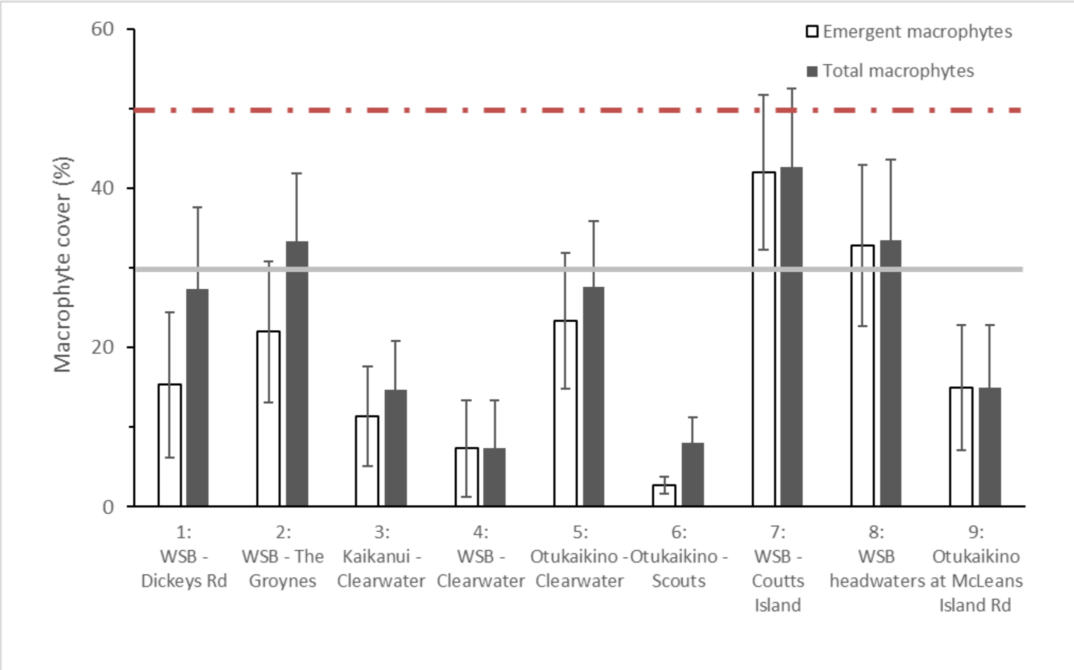


Figure 15: Mean (±1SE) macrophyte cover (emergent = white bars; total = grey bars) recorded at five locations along each of three transects at the nine sites surveyed within the Otukaikino River catchment in March 2017. The grey line indicates the LWRP guideline for 'spring-fed – plains waterways' of 30% cover of emergent macrophytes; the red dashed line is the LWRP guideline for maximum total cover of macrophytes (emergent and submerged) of 50%.

Filamentous algae

Long (>20 mm) filamentous algae were rare in, or absent from, most sites surveyed, with the greatest total cover estimated in Site 6: Otukaikino Creek at Omaka Scout Camp (Figure 14). All sites were well below the Waimakariri RRP water quality standards which set a maximum value of 40% filamentous growths or mats. Site 9: Otukaikino Creek at McLeans Island Road had the highest cover of thick mat algae, as well as having the highest cover in thin algae, this is not surprising as Site 9 had the lowest canopy cover, or shading, across all sites.

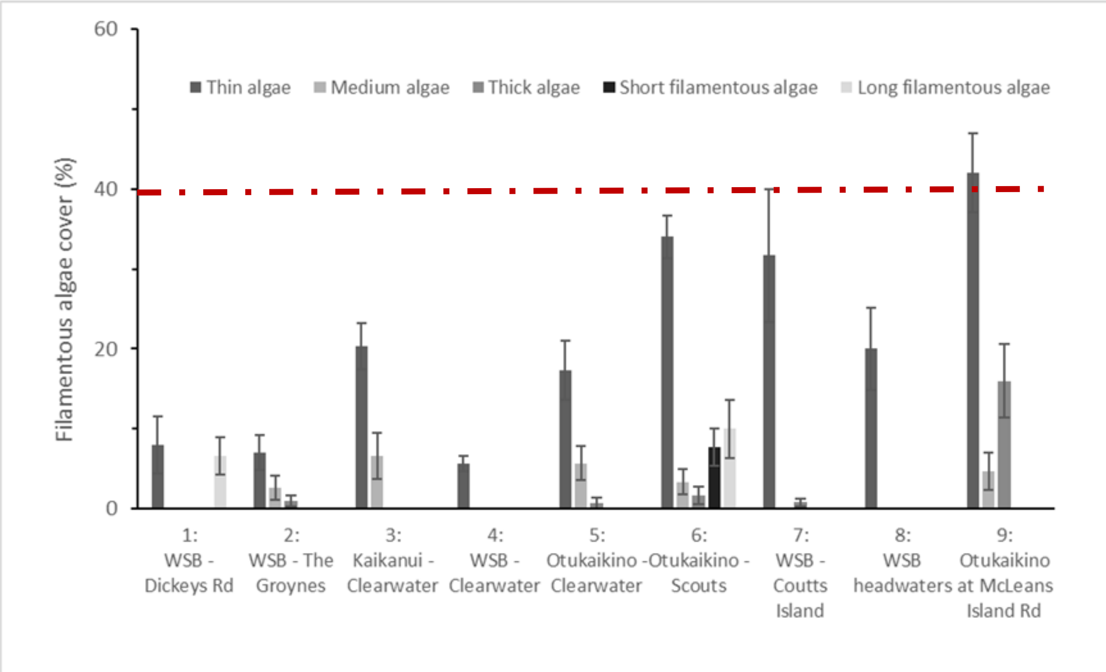


Figure 16: Mean (±1SE) algal cover recorded at five locations along each of three transects at the nine sites surveyed within the Ōtūkaikino River catchment in March 2017. The red dashed line is the maximum total cover (40%) of long filamentous algae cover recommended in the LWRP 'spring-fed – plains waterways' guidelines.

Sediment quality

Table 5 provides a summary of the grain size (%) composition found in the sediment sample collected from each site. Site 2: Waimakariri River South Branch at the Groynes dog park and Site 3: Kaikanui Creek downstream of Clearwater Resort had the highest proportion of silt/clay (<0.063mm) substrata, out of all the nine sites (Table 5). 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).

With the exception of Sites 3 and 7, 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). The concentration of zinc in the stream bed material at Site 3, and copper at Site 7, was above the ISQG-low ANZECC (2000) sediment quality guideline (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 concentrations of zinc and copper at Sites 3 and 7 were markedly greater (approx. at least 4-5 times greater) than that recorded at other sites. Site 3 was downstream of an urban development; Site 7 was on a dairy farm with no riparian buffer around waterway.

There are no listed ANZECC (2000) guidelines for total phosphorus (TP) or total organic carbon (TOC). However, the levels measured in the nine sites surveyed were similar to levels detected in other catchments within the Christchurch City limits (e.g. Halswell River – Boffa Miskell 2016; Heathcote River – NIWA 2015).

TP and TOC concentrations were variable across sites, ranging from 340 to 730 mg / kg TP; and 0.38 to 7.7 g / 100 g TOC. The highest concentration of both TP and TOC was recorded at Site 8: Waimakariri River South Branch headwaters (Table 5). This may indicate this site (and possibly others) might be impacted by contaminants such as fertilisers, pesticides, and industrial chemicals, all of which cause elevated TOC concentrations. However, Site 8 also had the highest sediment depth of all sites surveyed, and was not fenced so did not exclude stock from the waterway. TP can bind to sediments, so a high sediment cover could influence this reading. Canopy cover and overhanging vegetation was also high at this site, which could have influenced the TOC concentration. Therefore, these high readings of TP and TOC at Site 8 could also be from a natural source.

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. The highest recorded PAH concentration was at Site 1 (Table 5).

TOC across all sites was, on average, higher than other rural catchments in the wider Canterbury region, with values being more typical of urban catchments, such as the Avon and Heathcote Rivers (Golder Associates 2012). Moreover, the metal and PAH concentrations detected at all sites were comparatively low when considering concentrations detected in more urbanised waterways around Christchurch (e.g. Heathcote River catchment, Avon River catchment; Kingett Mitchell Ltd 2005; NIWA 2014, 2015; Halswell River catchment; Boffa Miskell 2016).

Semi-volatile organic compounds (SVOCs) were also found in very low concentrations, with many sites falling below laboratory detection limits[9] (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 coal, wood and petroleum products.

[9] Detection limits of SVOCs may vary if insufficient sample is available, or if dilutions were required, during laboratory analyses (see Appendix 1 for further details).

*Table 5: Particle size distribution (%), copper, lead, zinc, total organic carbon, total phosphorus, total polycyclic aromatic hydrocarbons (PAHs), and semi-volatile organic compounds (SVOCs) in the sediment samples, March 2017. *Total PAHs were normalised to 1% of TOC, as recommended by ANZECC (2000). WSB = Waimakariri South Branch. Laboratory detection limits for the SVOCs[9] were: Bis(2-ethylhexyl)phthalate: 0.5 mg / kg; Butylbenzylphthalate: 0.2 mg / kg; Di-n-butylphthalate: 0.2 mg / kg: Carbazole: 0.1 mg / kg; Dibenzofuran: 0.1 mg / kg.*

	Site 1: WSB – Dickeys Rd	**Site 2: WSB – the Groynes**	**Site 3: Kaikanui – Clearwater**	**Site 4: WSB – Clearwater**	**Site 5: Ōtūkaikino – Clearwater**	**Site 6: Ōtūkaikino – Scouts**	**Site 7: WSB – Coutts Island Rd**	**Site 8: WSB – Headwaters**	**Site 9: Ōtūkaikino – McLeans Island Rd**	**ANZECC (2000) guideline**	
										ISQG-low	**ISQG-high**
Grain size											
Silt / clay: <0.063 mm	10.5	33.9	49.9	10	2.2	2.3	16.7	14.7	3.9	-	-
Fine sand: 0.063 - 0.250 mm	63.4	43.2	29.7	53.1	21.6	31.8	26.9	25.6	48.0	-	-
Medium sand: 0.250 - 0.500 mm	10.2	10.3	8.9	23.9	14.5	16.0	3.8	8.0	14.5	-	-
Coarse sand: 0.500 - 2.00 mm	2.7	3.9	3.5	4.3	2.5	2	2.1	5.3	8.4	-	-
Gravel and cobbles: >2.00 mm	13.3	8.8	7.9	8.7	59.2	47.9	50.5	46.3	25.3	-	-
Copper (mg / kg)	4	11	23	6	6	5	84	10	4	65	270
Lead (mg / kg)	6	23	20	11	8	9	39	12	6	50	220
Zinc (mg / kg)	38	63	280	33	46	42	46	34	42	200	410
Total organic carbon (g / 100 g)	0.38	2.4	1.27	1.17	3	3.3	2.6	7.7	0.94	-	-
Total phosphorus (mg / kg)	340	540	590	350	470	470	410	730	390	-	-
Total PAHs (mg / kg)*	2.37	0.53	0.71	0.77	0.30	0.27	1.36	0.59	0.96	4	45
SVOCs (mg / kg)											
Bis(2-ethylhexyl)phthalate	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 1.1	< 1.4	< 0.5		
Butylbenzylphthalate	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.6	< 0.7	< 0.2		
Di-n-butylphthalate	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.6	< 0.7	< 0.2		
Carbazole	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10	< 0.1	< 0.3	< 0.4	< 0.1		
Dibenzofuran	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10	< 0.1	< 0.3	< 0.4	< 0.1		

Overall best and worst site

The sediment contaminant concentrations were ranked from best (1) to worst (5) for each of the contaminants measured. Where SVOCs concentrations were below detection limits[9], sites were ranked equally (1=)[10].

Sites 1 and 9 were ranked as the best sites overall (i.e. ranked first place across sediment contaminant concentrations (Table 6)). Site 7 was ranked last, with Sites 2 and 8, ranked second last equal, making these three sites the worst overall, based on sediment contaminant concentrations (Table 6). It is important to remember that, with the exception of zinc and copper at Sites 3 and 7, respectively, 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. *Where SVOCs were below the laboratory detection limits, sites were ranked equally (1=).*

	Site 1: WSB – Dickeys Rd	**Site 2: WSB – the Groynes**	**Site 3: Kaikanui – Clearwater**	**Site 4: WSB – Clearwater**	**Site 5: Ōtūkaikino – Clearwater**	**Site 6: Ōtūkaikino – Scouts**	**Site 7: WSB – Coutts Island Rd**	**Site 8: WSB – Headwaters**	**Site 9: Ōtūkaikino – McLeans Island Rd**
Copper (mg / kg)	1=	7	8	4=	4=	3	9	6	1=
Lead (mg / kg)	2	8	7	5	3	4	9	6	1
Zinc (mg / kg)	3	8	9	1	6=	4=	6=	2	4=
Total organic carbon (g / 100 g)	1	5	4	3	7	8	6	9	2
Total phosphorus (mg / kg)	1	7	8	2	5=	5=	4	9	3
Total PAHs (mg / kg)	9	3	5	6	2	1	8	4	7
SVOCs*	2=	7	2=	2=	2=	2=	8	9	1
Sum of ranks	19	45	43	23	29	27	50	45	19
Final rank	1=	7=	6	3	5	4	9	7=	1=

[10] Although detection limits for SVOCs were variable across sites, it was not possible to determine with certainty if a site with a detection limit of <1.4 had a greater or similar SVOC concentration to a site with a detection limit of <0.5. Thus, all sites where SVOCs were below detection limits (as provided by Hills Laboratories) were ranked equally.

Macroinvertebrate community

Overview

A grand total of 30,248 macroinvertebrates, belonging to 50 taxonomic groups, was collected from the 9 sites surveyed within the Ōtūkaikino River catchment in March 2017.

The most diverse macroinvertebrate group was the caddisflies (Trichoptera), with 13 different taxa found across the nine sites. The true flies (or two-winged flies, Diptera) was the next most diverse group, with 12 different taxa recorded at all of the survey sites, followed by snails and bivalves (Mollusca) with 6 taxa, crustaceans with 5 taxa, and two mayfly (Ephemeroptera) taxa.

As well as being the most diverse group, caddisflies also dominated (in abundance) the macroinvertebrate community collected. The stony-cased caddisflies *Pycnocentria evecta*, *Pycnocentrodes aureulus*, and the net-spinning caddis *Aoteapsyche colonica* were present in very high numbers at most sites.

Crustaceans, and snails and bivalves (e.g. the ubiquitous New Zealand mud snail *Potamopyrgus antipodarium*), were the next most abundant macroinvertebrate groups, overall.

Orthoclad midge larvae, *Deleatidium* mayfly nymphs, the snails *Physella* and *Potamopyrgus*, and the caddisflies *Hudsonema amabile*, *Hydrobiosis parumbripennis*, *Aoteapsyche colonica*, *Neuochorema forsteri*, *Oxyethira albiceps*, *Psilochorema bidens*, *Pycnocentria evecta*, *Pycnocentrodes aureulus* were present at all nine sites surveyed.

A single dobsonfly (*Archichauliodes diversus*) larva was found at Site 7: Waimakariri River South Branch off Coutts Island Road, but this species was not found at any other site. A single damselfly nymph (*Xanthocnemis zealandica*) was also found at Sites 1, 2 and 7.

Total abundance

The total number of macroinvertebrates (total abundance) collected was variable across sites, ranging from 6,593 in Site 1: Waimakariri South Branch upstream of Dickeys Road; to 1,916 in Site 3: Kaikanui Creek downstream of Clearwater Resort had the lowest (Figure 16).

The markedly greater total abundance found at Sites 1 and 6 was largely due to the high numbers of seed-shrimp ostracods (Crustacea: Ostracoda), *Potamopyrgus antipodarum* mud snail (Mollusca), and the stony-cased caddis *Pycnocentrodes evecta*, which dominated the communities at these sites.

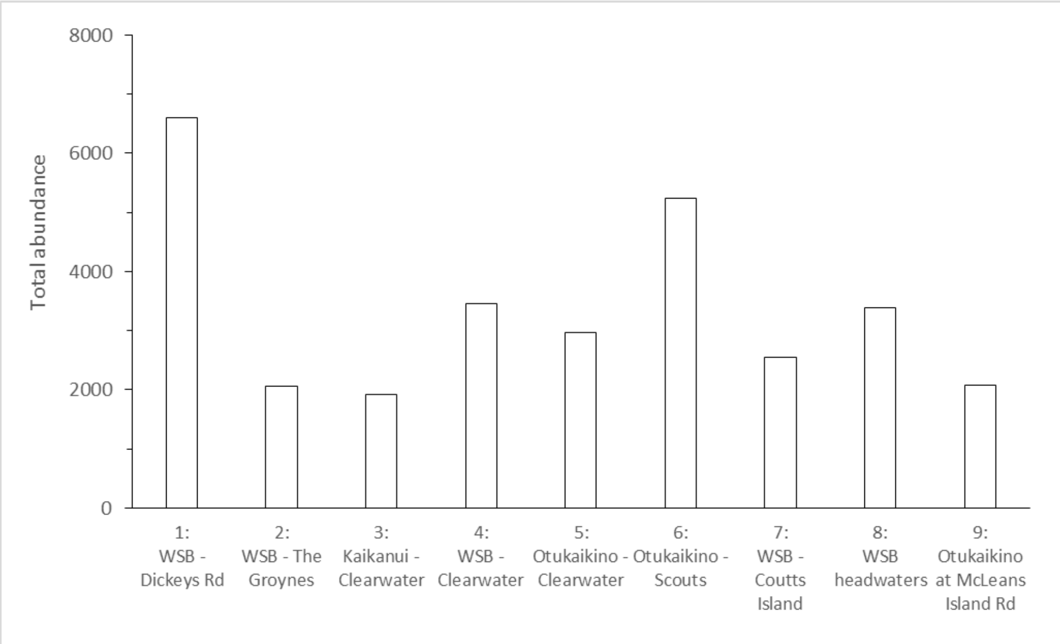


Figure 17: Total abundance of macroinvertebrates collected in a kick-net sample from each of the nine sites surveyed in the Ōtūkaikino River catchment in March 2017.

Taxonomic richness

Taxonomic richness was generally similar across sites, ranging from 23 to 30 macroinvertebrate taxa (Figure 17). Site 6 had the greatest taxonomic richness (30 taxa), followed by Site 1, 2 and 7, all of which had 29 macroinvertebrate taxa. Site 3 (23 taxa) and Site 8 (24 taxa) had the least diverse macroinvertebrate community.

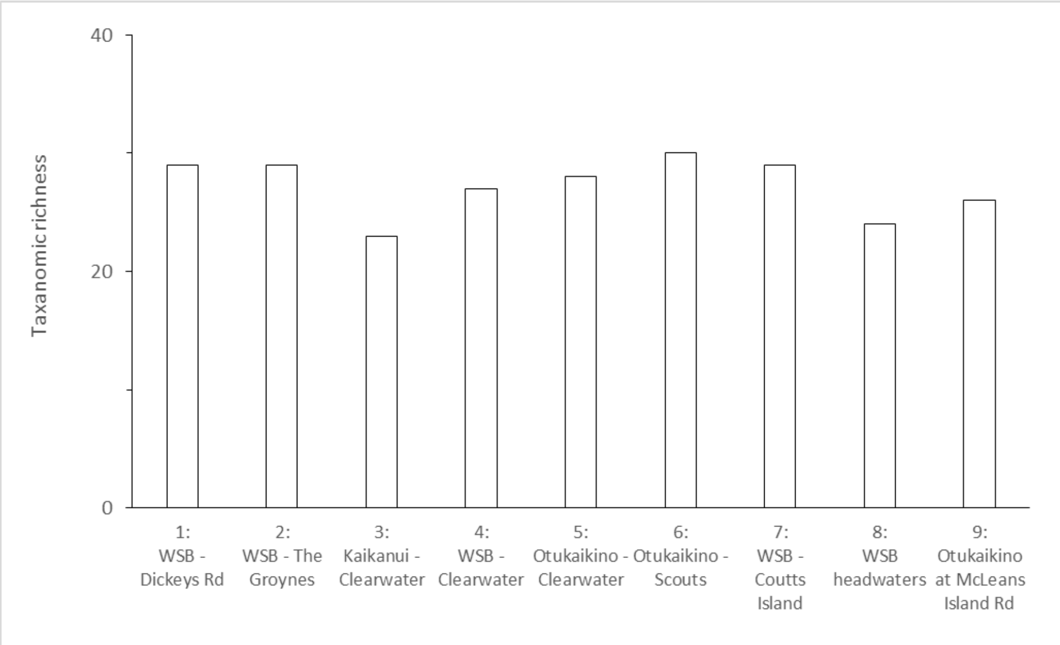


Figure 18: Taxonomic richness of macroinvertebrates collected in a kick-net sample from each of the nine sites surveyed in the Ōtūkaikino River catchment in March 2017.

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 nine sites, ranging from 13 taxa (at Sites 1, 2 and 4) to 10 EPT taxa (at sites 3 and 8) (Figure 19).

Caddisflies were found at all sites, as was the mayfly *Deleatidium*. The only other mayfly taxa found, *Coloburiscus*, was found at 5 of the nine sites surveyed. Stoneflies were never found at any of the sites surveyed.

The purse-cased caddisflies *Oxyethira albiceps*, which belongs to the pollution-tolerant family Hydroptilidae, were encountered at 100% of the sites surveyed (Figure 19).

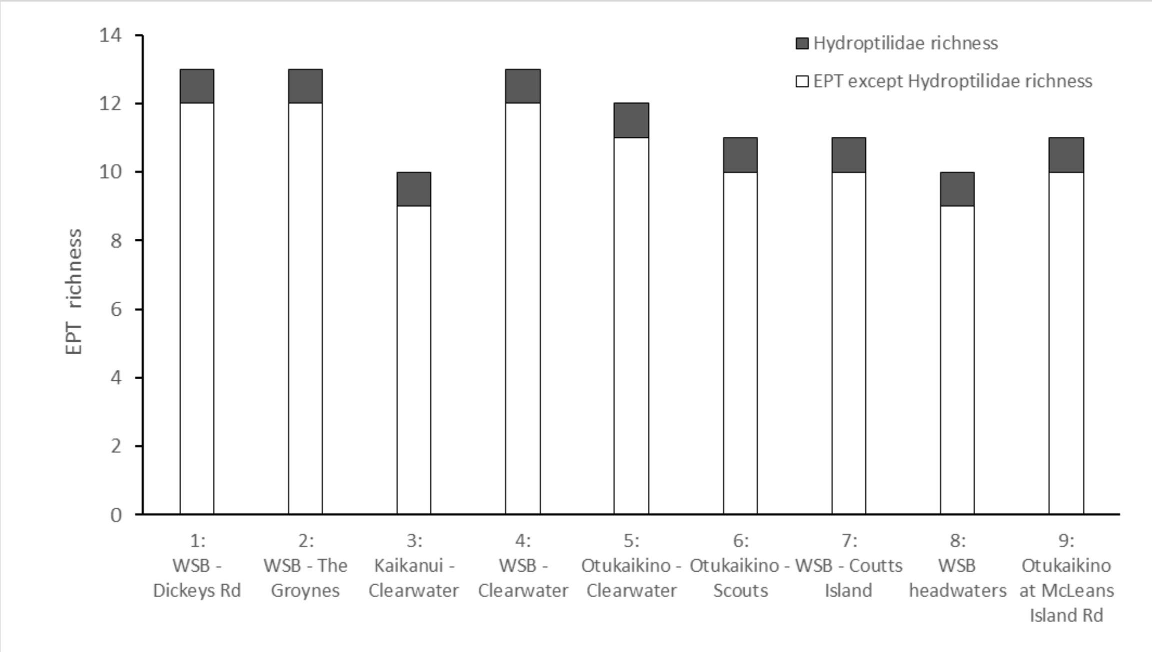


Figure 19*: Total richness of EPT taxa collected in a kick-net sample from each of the nine sites surveyed in the OtukaikinoRiver catchment and in March 2017. Grey bars indicate EPT richness excluding hydroptilidae, while the white bars indicate EPT richness minus the pollution-tolerant Hydroptilidae caddisflies.*

EPT abundance

EPT abundance was variable across sites. Site 1: Waimakariri River South Branch upstream of Dickeys Road had the lowest EPT abundance, with EPT taxa only making up 10% of the total number of macroinvertebrates caught at the site. Site 8: Waimakariri River South Branch headwaters had the highest EPT abundance, followed by Sites 3, 6, and 7, and the macroinvertebrate community was dominated by EPT taxa (Figure 20).

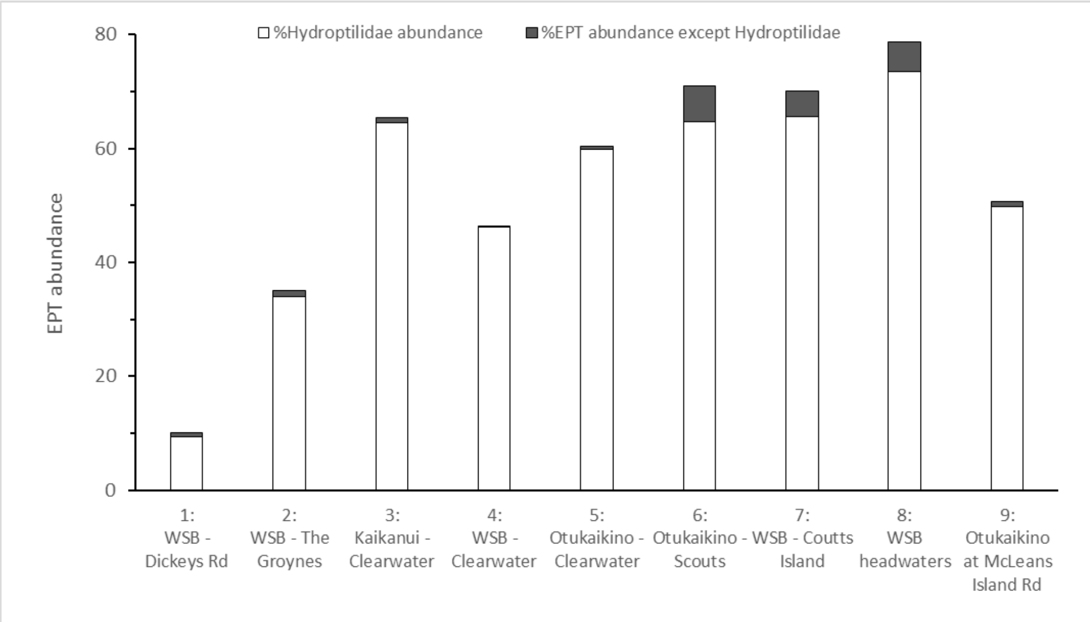


Figure 20: Total abundance of EPT taxa collected in a kick-net sample from each of the nine sites surveyed in the Ōtūkaikino River catchment in March 2017. Total bar height (i.e. white and grey combined) indicate EPT richness, while grey bars indicate EPT richness minus the pollution-tolerant Hydroptilidae caddisflies.

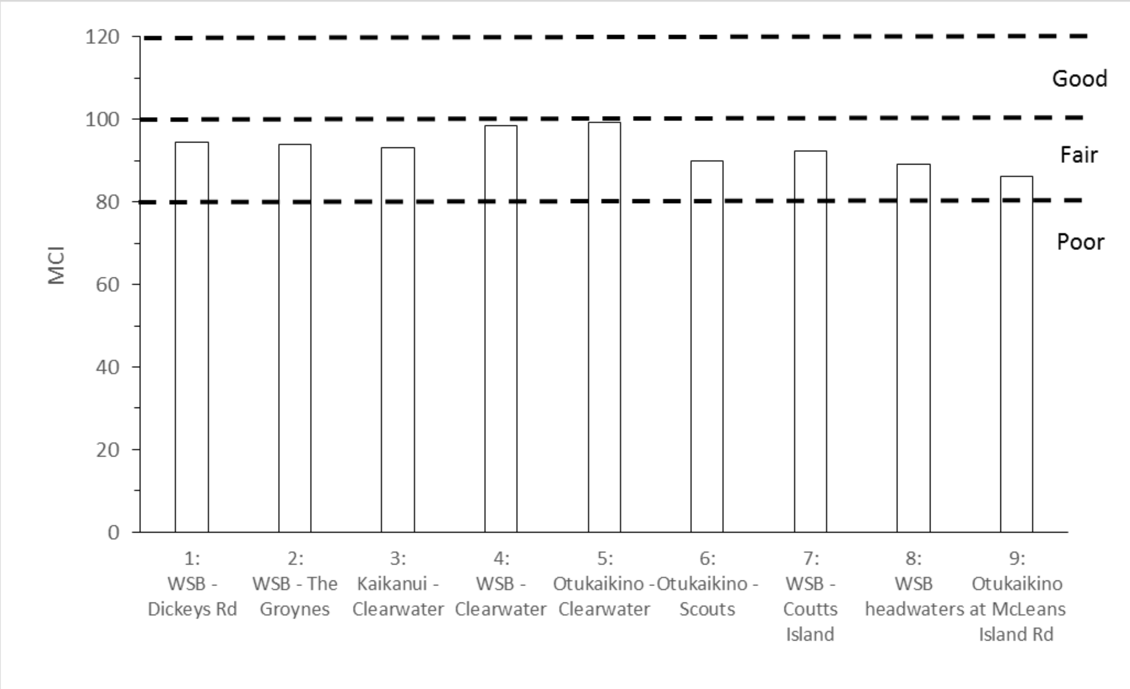
Macroinvertebrate Community Index

There was little variability in MCI scores across the nine sites surveyed and all sites had “fair” stream health with “probable moderate pollution” (based on the water quality categories of Stark and Maxted 2007) (Figure 21).

Site 9: Ōtūkaikino Creek at McLeans Island Road had the lowest MCI score of 86.2, while Site 5: Ōtūkaikino Creek at Clearwater Resort had the highest of 99.3. Note, the threshold for “good” stream health is an MCI of 100, which Sites 4 and 5 almost fell within.

QMCI, which is considered a better indicator of “health”, than MCI, as it takes into account abundance and presence of macroinvertebrate taxa, showed slightly different results, with only Site 9: Ōtūkaikino Creek at McLeans Island Road having “fair” stream health, indicating “probable mild enrichment”. All other sites, except Site 8: Waimakariri River South Branch headwaters, had “good” water quality, indicating “doubtful quality or possible mild pollution”. Site 8 had “excellent” water quality, indicating “clean-water” (Figure 21).

All sites, except Site 9: Ōtūkaikino Creek at McLeans Island Road, were above the LWRP guideline for spring-fed (plains) waterways of a minimum QMCI of 5 (Figure 21).



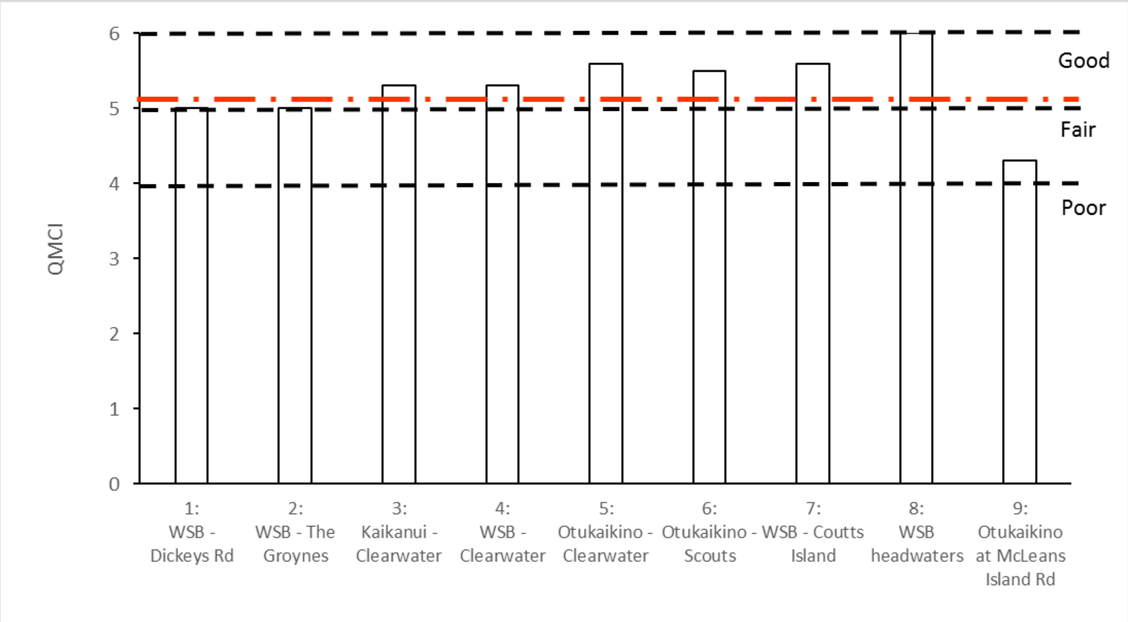


Figure 21: MCI (top) and QMCI (bottom) scores for the nine sites surveyed in the Ōtūkaikino River catchment in March 2017. The dashed lines indicate the water quality categories of Stark and Maxted (2007), where "poor" = "probable severe enrichment", "fair" = "probable moderate enrichment", and "good" = "doubtful quality or possible mild enrichment". The "excellent" category is above the top dotted line. The red line on the QMCI graph indicates the LWRP minimum QMCI value for Freshwater Outcomes for Spring-fed Plains Waterways.

Overall best and worst sites

When the biotic indices of taxonomic richness, EPT richness, %EPT abundance, and QMCI scores, for each of the nine sites surveyed, were ranked from 1 (best) to 9 (worst), Site 6: Ōtūkaikino Creek at Omaka Scout Camp and Site 7: Waimakariri River South Branch at Coutts Island Road were ranked as the best sites overall (i.e. ranked first place equal across all four indices (Table 7). Site 9: Ōtūkaikino Creek at McLeans Island Road 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 9 (worst) for each of the nine site surveyed in March 2017. 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 abundance	QMCI	Sum of ranks	Final rank
Site 1: WSB – Dickeys Rd	2= (29)	1= (13)	9 (10.1)	7= (5.0)	19	6=
Site 2: WSB – the Groynes	2= (29)	1= (13)	8 (34.9)	7= (5.0)	18	4=
Site 3: Kaikanui – Clearwater	9 (23)	8= (10)	4 (65.3)	5= (5.3)	26	8
Site 4: WSB – Clearwater	6 (27)	1= (13)	7 (46.4)	5= (5.3)	19	6=
Site 5: Ōtūkaikino – Clearwater	5 (28)	4 (12)	5 (60.4)	2= (5.6)	16	3
Site 6: Ōtūkaikino – Scouts	1 (30)	5= (11)	2 (71.0)	4 (5.5)	12	1=
Site 7: WSB – Coutts Island Rd	2= (29)	5= (11)	3 (70.0)	2= (5.6)	12	1=
Site 8: WSB – Headwaters	8 (24)	8= (10)	1 (78.6)	1 (6.0)	18	4=
Site 9: Ōtūkaikino – McLeans Island Rd	7 (26)	5= (11)	6 (50.6)	9 (4.3)	27	9

Changes in macroinvertebrate community over time

Taxonomic richness and QMCI scores

Taxonomic richness and EPT richness, at the site level, were generally greater in 2017 (this study) than in 2012 (EOS Ecology 2012) (Figure 23). However, overall taxon richness (i.e. the total number of taxa found in each survey year) declined from a total of 67 macroinvertebrates collected in 2008, to 58 in 2012, and 50 in 2017. A similar pattern was seen for EPT taxa with 20, 19, and 15 EPT taxa found in 2008, 2012, and 2017, respectively. These declines over time could be attributed to differences in sampling effort[3].

The stonefly *Zelandobius*, which was found in 2008 and 2012, was not found in 2017. Also, two species of the caddisfly *Hydrobiosis* (*Hydrobiosis parumbripennis* and *H. clavigera*) were found in 2012, while only *H. parumbripennis* was found in 2017; and both *Hudsonema alienum* and *Hu. amabile* were found in 2012, but only *Hu. amabile* found in 2017. This may be of concern (with the potential for rare taxa, such as *Zelandobius*, *H. clavigera*, and *Hu. alienum* to be declining). Differences in total number of taxa may also be attributable, in part, to differences in taxonomic resolution. For example, EOS Ecology (2008, 2012) included the caddisfly taxa *Hydrobiosis*, when larvae could not be accurately identified to species level. This genus of caddisfly was counted as an additional caddis taxon.

There were also some noteworthy differences in QMCI scores among the 2008, 2012 (EOS Ecology 2008, 2012) and 2017 (this study) surveys. QMCI was generally greater in 2017, than the previous survey years, with the exception of Site 1: Waimakariri River South Branch upstream of Dickeys Road and Site 3: Kaikanui Creek downstream of Clearwater Resort (Figure 23).

QMCI scores were predominantly of “fair” stream health in 2008 and 2012, while in 2017 they were found to be generally of “good” stream health (Figure 23). Site 6: Ōtūkaikino Creek at Omaka Scout Camp showed the greatest change over time; it was found to have “poor” water quality and stream health in 2008, but “good” water quality and stream health in 2017. Site 8: Waimakariri River South Branch headwaters increased from the “fair” category in 2008 and 2012, to on the cusp of the “excellent” category in 2017.

While these differences may indicate an improvement in stream health, QMCI scores can be highly variable through time. This is because 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, differences in QMCI of the magnitude detected in this study (between 2012 and 2017) may not reflect ecologically relevant change in macroinvertebrate community composition.

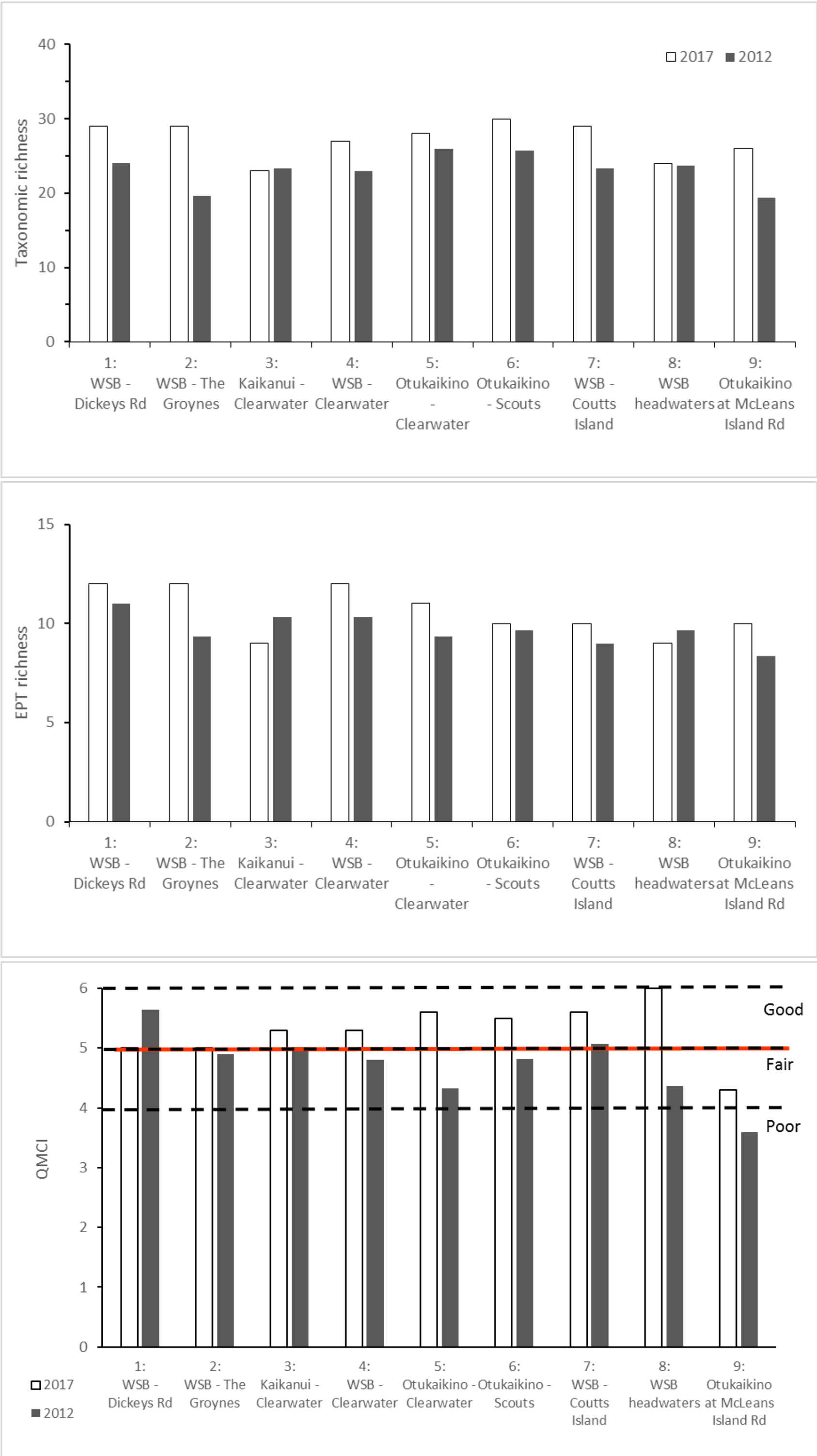


Figure 22: Taxonomic richness (top), EPT richness (middle), and QMCI scores (bottom) found at the nine sites surveyed in 2012 (grey bars; EOS Ecology) and 2017 (white bars; this study). The dashed lines on the QMCI graph indicate the water quality categories of Stark and Maxted (2007) of "poor"", "fair", and "good" (see Table 3). The "excellent" category has not been shown. The red line indicates the Canterbury LWRP minimum QMCI value (of 5) for Freshwater Outcomes for Spring-fed Plains Waterways.

Community composition

Although there was some variability in macroinvertebrate community composition among the nine sites and through time (i.e., 2012 versus 2017), differences were largely due to variance in relative dominance (percent abundance) of caddisflies, and 'other'[11] taxa. Caddisflies made up a small proportion of the community at all sites in 2012 (EOS Ecology 2012), compared to a much greater proportion of the community at all sites in 2017 (this study) (Figure 23). The dobsonfly *Archichauliodes* was found at Site 7 in 2017 (this study), but was not found at any sites in 2012 (EOS Ecology 2012).

Site 1: Waimakariri River South Branch upstream of Dickeys Road, showed a distinct change in community composition between 2012 and 2017. The 2012 (EOS Ecology) results showed relatively high proportions of mayflies and caddisflies, however, in 2017 (this study) the community was largely dominated by ostracods, which made up 5,160 of the total 6,593 individuals found in the kick-net sample collected from the site.

It is important to note that stoneflies were found in the survey sites in 2012, but were never found in this study (2017).

[11] Macroinvertebrate taxa that made up only a small proportion of the community were grouped together in the 'other' category. These included, aquatic mites (Acarina), *Hydra* (Cnidaria), nematodes (Nematoda), aquatic worms (Oligochaete), leeches (Hirudinea), flatworms (Platyhelminthes), damselflies (*Xanthocnemis*), beetles (Elmidae), toe biters (Megaloptera; Archichauliodes), and aquatic bugs (*Microvelia*).

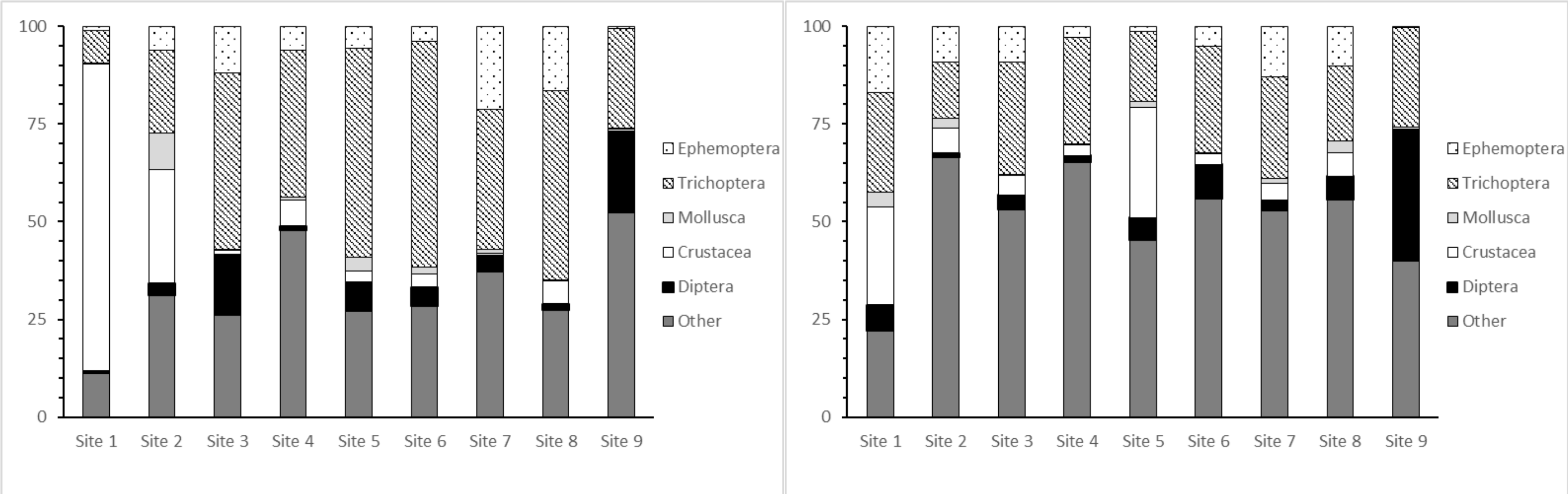


Figure 23: Macroinvertebrate community composition (%) found at the nine sites surveyed in March 2017 (left) and March 2012 (EOS Ecology, right). "Other" included aquatic mites (Acarina), Hydra *(Cnidaria), nematodes (Nematoda), aquatic worms (Oligochaete), leeches (Hirudinea), flatworms (Platyhelminthes), damselflies (*Xanthocnemis*), beetles (Elmidae), toe biters (Megaloptera;* Archichauliodes*), and aquatic bugs (*Microvelia*).*

The NMDS[12] ordination, confirmed by the ANOSIM results (ANOSIM R = 0.165; P = 0.013), indicated that there were only subtle (but statistically significant) differences in the macroinvertebrate community found at sites in 2017 (this study) compared to 2012 (EOS Ecology 2012) (Figure 24).

SIMPER indicated that these significant differences in community composition were largely due to differences in the average number of occurrences of some taxa (i.e. greater or lesser numbers of individuals), rather than the absence of a particular taxon from one sampling occasion. For example, the stony-cased caddisfly, *Pycnocentria evecta*, was twice as abundant in 2017 than 2012, while *Pycnocentrodes aureulus* was more abundant in 2012 than 2017. The native mud snail *Potamopyrgus antipodarum* was nearly twice as abundant in 2012 than 2017 (see Appendix 2 for further details on SIMPER results).

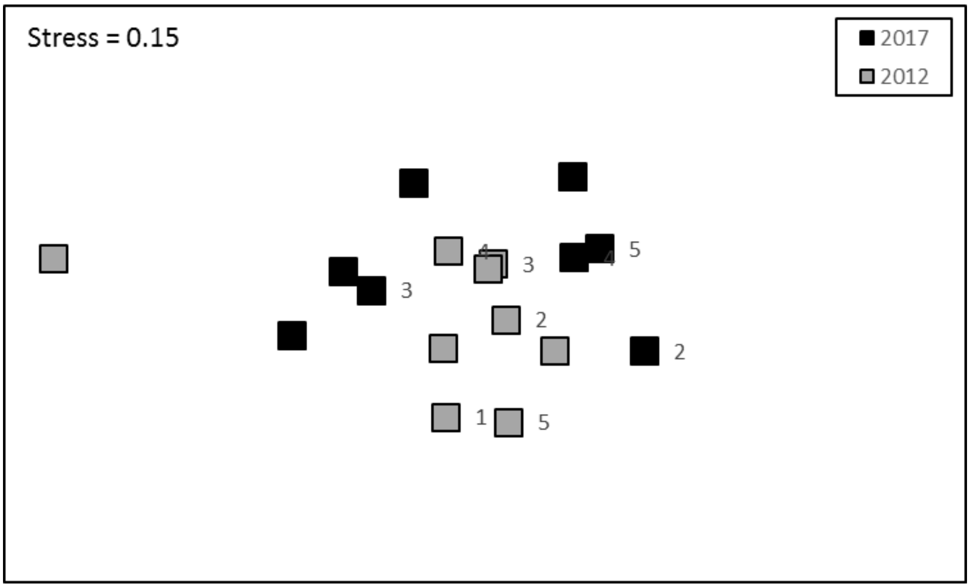


Figure 24: Non-metric multidimensional scaling (NMDS) ordination based on a Bray-Curtis matrix of dissimilarities calculated from macroinvertebrate abundance data collected from the nine sites surveyed in March 2012 (grey squares; EOS Ecology 2012) and in March 2017 (black squares; this study). Axes 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 208 fish, belonging to 7 species, were captured in the nine sites surveyed within the Ōtūkaikino River catchment in March 2017. The species captured were, in descending order of total abundance (i.e. across all sites): upland bully (*Gobiomorphus breviceps*), shortfin eel (*Anguilla australis*), longfin eel (*A. dieffenbachii*), common bully (*G. cotidianus*), brown trout (*Salmo trutta*), giant bully (*G. gobioides*) and inanga (*Galaxias maculatus*).

Longfin eel and inanga have a conservation status of “at risk, declining”, upland bully, giant bully, common bully, and shortfin eel are currently listed as “not threatened”, and brown trout is an introduced and naturalised species (Goodman et al. 2013).

[12] The NMDS ordination gave a good representation of the actual community dissimilarities between 2012 (EOS Ecology) and 2017 (this study), with a two-dimensional stress value of 0.15.

Species richness

The fish communities were depauperate, with species richness generally around three to five fish species present at a site. Site 3: Kaikanui Creek downstream of Clearwater Resort had the most diverse freshwater fish community with five species found, whereas Site 6: Ōtūkaikino Creek at Omaka Scout Camp and Site 8: Waimakariri River South Branch headwaters had the fewest species with only three species being found at these sites.

Upland bullies were the most commonly encountered species, and were found at all sites, except for Site 1: Waimakariri River South Branch upstream of Dickeys Road. The fish community Site 1 was surveyed using traps and nets, rather than electric fishing. Longfin eels were found at all sites except for Site 2: Waimakariri River South Branch at the Groynes dog park. Shortfin eels were not found at Sites 1 and 6, while giant bullies were only found at Site 1 and inanga was only found at Site 2 (Table 8).

Size distribution of fish

Table 8 summarises the size and species richness information of fish captured (or seen but not captured) at the nine sites surveyed in March 2017. The largest fish captured at any site was a 1,000 mm longfin eel at Site 1: Waimakariri River South Branch upstream of Dickeys Road.

Longfin eels (an “at risk, declining” species), which have previously been reported as less frequently found in the Ōtūkaikino catchment (Aquatic Ecology, 2013), was found at 89% of (8 of 9) sites and in similar numbers to the “not threatened” shortfin eel. The high number of upland bullies that were caught were predominantly from Site 6: Ōtūkaikino Creek at Omaka Scout Camp, where 79 of the 124 bullies caught for the whole study were found. These fish ranged in size from 30 to 70 mm, a high proportion of which were below 50 mm indicating a high juvenile population. The larger bullies (between 90 and 120 mm) were relatively uncommon, in comparison, with only 3 giant, 2 common, and 2 upland bullies in this size range found. Inanga was only caught at one site, but was seen (and not caught) at Site 3. It is important to note that the presence / abundance of inanga and larger brown trout are underestimated by electric fishing techniques, so these species may have been more abundant across the catchment than shown in Table 5.

*Table 8: Total number of fish caught (or seen) at each of the nine sites surveyed in March 2017. 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.*

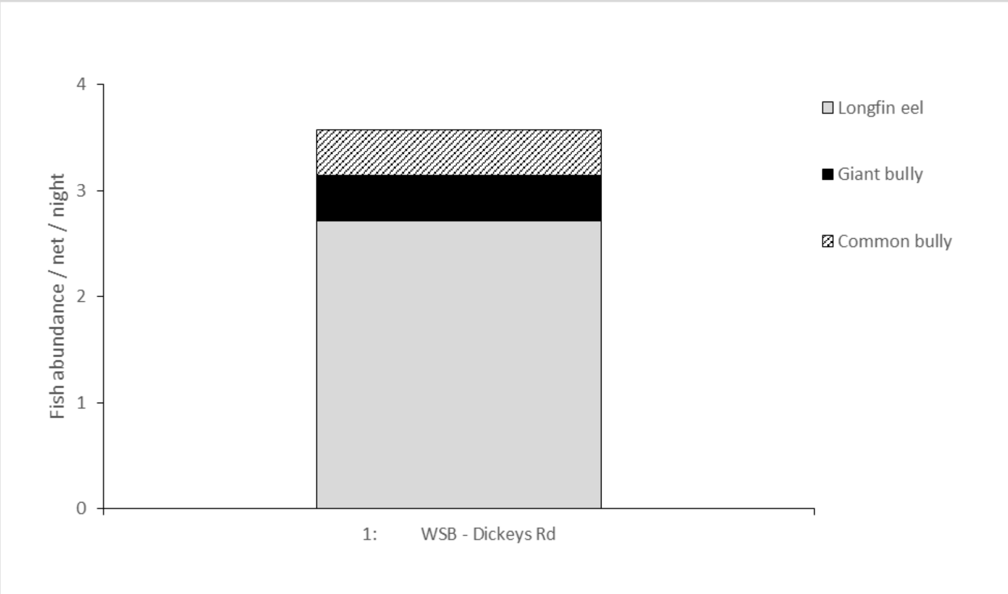
	Fishing method	Common bully	Upland bully[13]	Longfin eel	Shortfin eel	Eel species	Inanga[14]	Brown trout	Giant bully
Site 1: WSB -Dickies Rd	Traps	3 (60-80)	0	19 (300-1000)	0	1 (120)	0	0	3 (90-120)
Site 2: WSB – The Groynes	EFM	3 (60-120)	1 (50)	0	3 (180-350)	0	1 (80)	0	0
Site 3: Kaikanui - Clearwater	EFM	3 (60-100)	2 (90)	1 (550)	5 (150-330)	4 (150-230)	0	0	0
Site 4: WSB - Clearwater	EFM	1 (35)	8 (45-65)	1 (380)	1 (380)	0	0	0	0
Site 5: Otukaikino – Clearwater	EFM	0	4 (45-60)	1 (380)	10 (150-380)	1 (100)	0	0	0
Site 6: Otukaikino – Scouts	EFM	0	79 (30-70)	2 (350-500)	0	0	0	1 (90)	0
Site 7: WSB – Coutts Island Rd	EFM	0	3 (30-70)	1 (300)	2 (150-250)	0	0	5 (100-130)	0
Site 8: WSB -Headwaters	EFM	0	23 (20-75)	1 (700)	3 (250-300)	0	0	0	0
Site 9: Otukaikino – McLeans Island Rd	EFM	0	4 (60-70)	1 (350)	9 (180-350)	0	0	1 (120)	0

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

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

Community composition

Upland bullies, longfin and shortfin eels were the most commonly encountered species (Figure 25). Longfin eels dominated the community at Site 1: Waimakariri River South Branch upstream of Dickeys Road, while upland bullies made up most of the fish community at Sites 4, 6, and 8. Shortfin eels were also present at the majority of the sites, being found at all sites except Site 1 and 6.



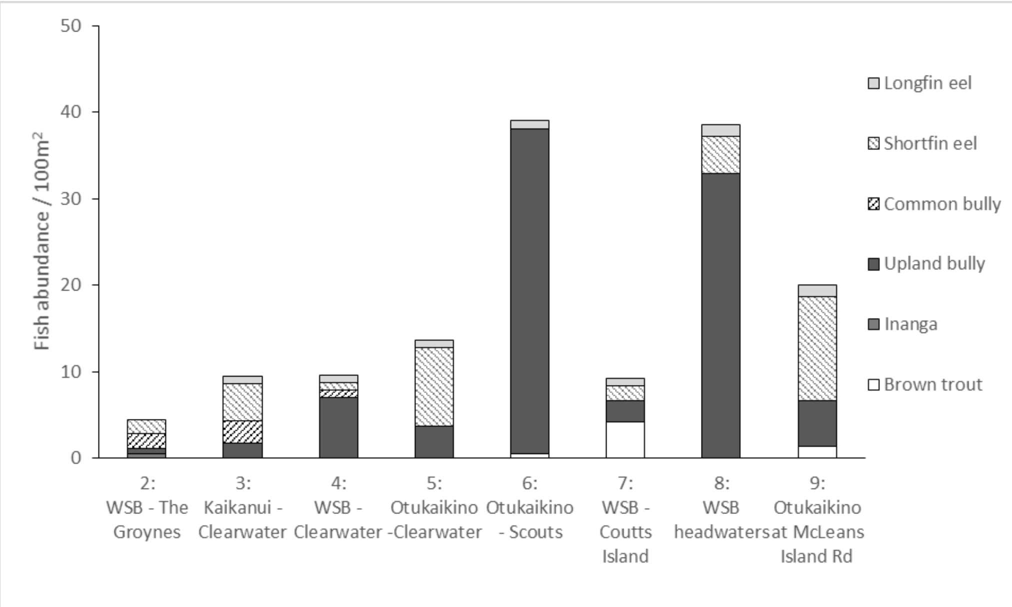


Figure 25: Total abundance of fish, separated by species, captured at each of the nine sites surveyed in March 2017. Numbers are show as catch per unit effort (CPUE): per 100 m^2 of waterway surveyed using electric fishing (top); or per net / night where traps and nets were set overnight (bottom). Note, the fish community at Site 1 was surveyed using traps and nets, while all other sites were surveyed using electric fishing techniques.

Changes in fish community over time

Of the sites that were able to be compared, there were slight differences in both species richness and community composition in 2011 (Aquatic Ecology Ltd 2013) and 2017 (this study) (Table 9). Generally, more species and numbers of fish were found in 2017, than in 2011 (Aquatic Ecology 2013) (Table 9).

Species richness of the 2013 sites was between 2 and 3, whereas the richness of the 2017 sample sites was between 3 and 5. The species found in 2017 but not in 2013 were Common bully (*Gobiomorphus cotidianus*), giant bully (*G. gobioides*), and inanga (*Galaxias maculatus*). All species found in 2013 were also found in 2017 and these included shortfin eel (*Anguilla australis*), upland bully (*G.s breviceps*), brown trout (*Salmo trutta*) and longfin eel (*A. dieffenbachia*).

Upland bully was the species with the highest catch numbers both sampling periods with 43 and 124 being caught in 2013 and 2017 respectively. Longfin eels were also detected in greater numbers in 2017, than 2013. More brown trout (*Salmo trutta*) were found in 2013 than in 2017 (this study). It is important to note that the total catch number in 2013 was 81 fish, compared to the total catch number in 2017 which was 211.

Table 9: Fish species, including dominant species (based on abundance data), and richness found at four sites surveyed in this study (Boffa Miskell 2017) and previous work commissioned by the Christchurch City Council (Aquatic Ecology Ltd 2013). Sites from 2013 did not match up with the 2017 sites however the closest and most suitable sites from the 2013 sampling were used as comparisons.

Site number and name	Species found in 2017 (this study)	Species found in 2011 (Aquatic Ecology Ltd 2013)
Site 4: **WSB - Clearwater**	Dominant species: upland bully Upland bully, **common bully**, longfin eel, shortfin eel Richness = 4	Dominant species: upland bully, Upland bully, longfin eel, shortfin eel, **brown trout** Richness = 4
Site 5: **Ōtūkaikino – Clearwater**	Dominant species: shortfin eel **Upland bully, longfin eel,** shortfin eel Richness = 4	Dominant species: shortfin eel **Brown trout**, upland bully, shortfin eel Richness = 3
Site 6: **Ōtūkaikino – Scouts**	Dominant species: upland bully Upland bully, longfin eel, brown trout Richness = 3	Dominant species: shortfin eel Brown trout, upland bully, longfin eel, shortfin eel Richness = 4
Site 7: **WSB – Coutts Island Rd**	Dominant species: brown trout Upland bully, longfin eel, **shortfin eel**, , brown trout Richness = 4	Dominant species: upland bully Brown trout, longfin eel, upland bully Richness = 3

Discussion

Ecosystem health

This ecological assessment indicated that the sites surveyed within the Ōtūkaikino River catchment were generally of good ecological health. Of the nine sites surveyed, only one (Site 9: Ōtūkaikino Creek at McLeans Island Road) fell within the "fair" ecological health, or water quality, category. Site 8: was found to have "excellent" ecological health, or water quality, based on the macroinvertebrate community found. The remainder of sites surveyed were classified as of "good" ecological health. All sites, except Site 9, met the Canterbury LWRP for Freshwater Outcomes for Spring-fed plains waterways minimum QMCI of 5. Site 9 had a QMCI of 4.3. These findings differ from that found in the 2012 study (EOS Ecology 2012), where the majority of the sites surveyed were classified as having "fair" ecological health.

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 macroinvertebrate biotic indices, sites that were ranked as 'best' and 'worst' overall were not consistent. This may suggest that the ANZECC (2000) sediment quality guidelines adequately protect the species present in the catchment, as no sites exceeded the ISQG-high limits. That is, Sites 1 and 9 were ranked as 'best' overall with regards to sediment contaminant concentrations (i.e. had the lowest contaminant concentrations), while sites 2, 8 and 7 were ranked as 'worst' (i.e. had the highest contaminant concentrations). However, Sites 6 and 7 were found to be the 'best' sites when it came to the macroinvertebrate community present, and sites 3 and 9 were the 'worst' sites.

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 was relatively low across all sites and ranged between 52.6 and 68.9 µS/cm. pH was generally circum-neutral in all nine sites and, at the time of sampling, fell within the water quality standard for receiving waters of the LWRP. Water temperature was generally cool at all sites, and all were below the LWRP guideline of 20°C for Canterbury Rivers, the highest temperature recorded was 17.6˚C at Site 7: Waimakariri River South Branch off Coutts Island Road. Dissolved oxygen levels were relatively high at all sites, with sites 3 and 4 having the lowest dissolved oxygen (79% saturation), which was below the Waimakariri River Regional Plan Water Quality Standards of minimum of 80% saturation.

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 (e.g. dissolved oxygen) and water temperature, and the macroinvertebrate community is a much better indicator of long-term stream, or ecosystem, health. The CCC undertakes regular monitoring of water quality at three sites within the Ōtūkaikino River catchment. Results of this monitoring are reported in the CCC's annual monitoring report.

Riparian and in-stream habitat

Riparian and in-stream conditions were variable across the nine sites, however, were in relatively good condition. However, only Sites 1 and 2 were considered to have substantive riparian cover that would benefit in-stream conditions.

Compared to the previous 2012 survey (EOS Ecology 2012), the sites were relatively similar, although, some changes in the riparian cover were observed. Substrate indexes were high at all sites ranging from 4.1 to 5.9, indicating that the stream bed substrate was dominated by cobble and pebble substrates, with relatively little amounts of finer particles present. Site 8 had the lowest substrate index of 4.1.

Fine sediment (<2 mm diameter) covered between 5% and 45% of the stream bed at all sites, with Sites 1, 5 and 8 exceeding the Canterbury LWRP Freshwater Outcomes for Spring-fed Plains Waterways guideline of a maximum cover of 20%. Overall, sediment cover was relatively sparse and did not cover most of the stream bed, which meant coarser substrata such as cobbles were generally available 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 common at most sites. However, the majority of this overhanging vegetation was from exotic willows. Canopy cover, and stream shading, was relatively high across sites, except for sites 3, 7 and 9, which all had less than 10% canopy cover. The other sites ranged between 15% and 58% canopy cover.

Macrophyte and filamentous algal cover was generally low across all sites, with filamentous algae being found in only two sites (Sites 1 and 6). Macrophyte cover, at all sites, was below the LWRP Freshwater Outcomes for Spring-fed Plains Waterways (maximum of 50% total macrophyte cover) and filamentous algal cover, at all sites, was below the standard set by the WRRP Water Quality Standards (maximum cover of 40%).

Sediment quality

With the exception of Sites 1 and 7, the concentrations of key sediment contaminants were below ANZECC (2000) guidelines, indicating a low risk of adverse effects to aquatic life. Site 3 was downstream of an urban development, which may increase inputs of heavy metals such as zinc. Site 7 was on a dairy farm with no riparian buffer around waterway. Copper levels were elevated at this site, and this may reflect the use of this element in agricultural practices.

Sites 1 and 9 were ranked as the best sites overall, while sites 7, 2 and 8 were ranked as the worst sites, with respect to sediment contaminant concentrations. It is important to remember that, with the exception of zinc and copper at Sites 3 and 7, respectively, none of the sediment contaminants measured exceeded ANZECC (2000) guidelines.

Moreover, the metal and PAH concentrations detected at all sites were comparatively low when considering concentrations detected in urban streams within Christchurch (e.g. the Heathcote River and Avon River catchments (NIWA 2014; 2015), and the Halswell River catchment (Kingett Mitchell Ltd 2005; Boffa Miskell 2016)).

Macroinvertebrate community

Macroinvertebrates are an important and commonly used measure of stream, or ecosystem, health. This survey showed that the majority of the sites had “good” ecosystem health, or water quality. Only one site (Site 9) fell within the “fair” category, indicating probable moderate pollution, while one site (Site 8) was categorised as of "excellent" ecosystem health, indicating clean water.

The macroinvertebrate community was dominated (both numerically and diversity) by caddisflies, with the stony-cased caddis *Pycnocentria evecta* and the net-spinning caddis *Aoteapsyche colonica* being particularly abundant at most sites. The mayfly *Deleatidium* was also relatively abundant at the majority of sites surveyed. All of these species are considered to be relatively sensitive to pollution, and effects of urbanisation. In particular, mayflies, which were present at all sites surveyed, are no longer found in Christchurch's more urbanised waterways, such as the Heathcote and Avon Rivers.

While there were differences in the macroinvertebrate community composition found in 2012 (EOS Ecology 2012) and 2017 (this study), these differences were largely due to differences in abundances of taxa, rather than the presence, or absence, of taxa. However, a single dobsonfly (*Archichauliodes diversus*) larva was found at Site 7: Waimakariri River South Branch off Coutts Island Road, but this species was not found at any other site, nor was it found in the 2012 study. Of greater interest, the stonefly *Zelandobius* was encountered at three sites in 2008 (Sites 5, 7, and 9) but just one site (Site 8) in 2012 (EOS Ecology 2008, 2012).The apparent loss of this clean-water insect group, and potentially other EPT taxa (e.g. *Hydrobiosis alienum*, *Hydrobiosis clavigera*), may be indicative of changes to the ecological health of the Ōtūkaikino River catchment.

Although only detected in low abundances in 2008 and 2012, it is of concern that stoneflies were not found in the Ōtūkaikino River catchment in 2017. The Ōtūkaikino River was the only remaining river in the Christchurch metropolitan area that still supported stoneflies (Greg Burrell, CCC Waterways Ecologist, *pers. com*). It appears that representatives of this clean-water insect group may no longer be present. However, it could also be that stoneflies remain in only very low abundances, and are, therefore, difficult to detect without a high level of sampling effort (i.e. increased number of samples, increased sampling area, or highly targeted sampling of specific habitat types).

Generally speaking, the pollution-sensitive or "clean-water" EPT taxa were largely represented by caddisflies (including some of the more tolerant taxa), but more sensitive mayflies were also found at all sites. The more "pollution-tolerant" hydroptilid caddisflies, *Oxyethira albiceps* were found at all sites within the Ōtūkaikino catchment.

It is noteworthy that a greater area was sampled in 2008 and 2012 versus 2017[3] , and it is expected that taxonomic richness would be greater because of this (i.e. based on the species-area relationship; Peay et al 2007). However, taxonomic richness appeared to be greater in 2017 (at the site level) than previous years (2008 and 2012). This could be due to differences in taxonomic resolution when identifying species in the laboratory.

When ranked according to four biotic indices, Site 6: Ōtūkaikino Creek at Omaka Scout Camp and Site 7: Waimakariri River South Branch off Coutts Island Road were considered the best sites overall, while Site 3: Kaikanui Creek at Clearwater and 9: Ōtūkaikino Creek at McLeans Island Road were ranked as the worst sites overall, when considering the macroinvertebrate communities present in 2017.

Fish community

Indigenous fish species were present at all nine sites within the Ōtūkaikino River catchment. Most importantly, all sites, except one, supported longfin eels, an "at risk, declining" species. Inanga, another "at risk, declining" species was also found in the catchment (Site 2: Waimakariri

River South Branch at the Groynes dog park). Inanga may have been present at other sites, however, inanga can be underestimated using electric fishing techniques (Joy et al. 2013).

Giant bullies, were only found at one of the sites surveyed in this study, despite the presence of what is likely to be this species' preferred habitat (e.g. undercut banks, overhanging vegetation and deeper water). This may be a reflection of the sampling methods used as the giant bullies were caught at Site 1: Waimakariri River South Branch upstream of Dickeys Road, which was surveyed using nets and traps, rather than electric fishing. Upland bullies were the most common species found throughout the sites, except at Site 1: Waimakariri River South Branch upstream of Dickeys Road. Upland bullies can tolerate a range of habitats, however, are commonly found in stony-bottomed streams such as was found at the sites in this catchment.

The fish community does not appear to have changed over time. When comparing results from 2011 (Aquatic Ecology 2013) and 2017 (this study), all species caught in 2011 were also caught in 2017. However, there were a few species that were caught in 2017 that had not been found in the 2011 study (Aquatic Ecology 2013). For example, longfin eels were caught at Site 7 in 2017, but were not encountered in 2013. Brown trout were recorded in the sites surveyed in 2011, however, were only found in Sites 6, 7, and 8 in 2017.

It is important to note the sites surveyed during 2011 (Aquatic Ecology 2013) did not exactly match up with the sites surveyed in 2017 (this study). Sites from 2011 that were close enough in proximity and deemed as relatively similar to sites from 2017 were used as comparisons. However, this only allowed for comparisons of four sites surveyed in both 2011 and 2017 (Sites 4, 5, 6, and 7).

Conclusions

Riparian and in-stream conditions appear relatively unchanged within the Ōtūkaikino River catchment. While there were some subtle site-by-site differences detected through time, generally ecological health was found to be similar in 2017 to that found in previous surveys.

In particular, EPT diversity is still relatively high, with mayflies and caddisflies present in both 2012 and 2017. However, the stonefly *Zelandobius*, which was found in low numbers at three sites in 2008 and in one site in 2012, may no longer be present in the Ōtūkaikino River catchment. Further investigation into the stonefly, and other clean-water EPT taxa, should be undertaken to determine whether these groups still remain in the Ōtūkaikino River.

The Ōtūkaikino River catchment also continues to support a range of freshwater fish species, including the "at risk, declining" species, inanga and longfin eels.

Continued focus on treatment of stormwater prior to input into, and management of land-use change in, the Ōtūkaikino River catchment is key to maintaining the good to excellent ecological health (and in particular the pollution-sensitive EPT taxa).

Recommendations

- Best practice stormwater management techniques should be considered, especially when urban development in the area is increasing. Untreated, or poorly treated, stormwater can bring fine sediments and contaminants into waterways, which smother the stream bed and can be directly consumed by freshwater fauna. Reducing inputs of fine sediments is essential when enhancing and protecting habitat for aquatic species such as pollution-sensitive macroinvertebrate taxa, and many freshwater fishes. This is especially important for the Ōtūkaikino River catchment where EPT taxa, including mayflies (and possibly stoneflies) still occur.
- Enhancement of the riparian margins, particularly at sites where minimal riparian buffer is observed, may assist in maintaining and improving ecological health of the Ōtūkaikino River catchment. Only two sites, out of the nine sampled, (Site 1: Waimakariri River South Branch upstream of Dickeys Road; and Site 2: Waimakariri River South Branch at the Groynes dog park) had riparian zones with indigenous species. Site 8 was not fenced and was open to stock. The riparian zones at the rest of the sites largely consisted of mown or pasture grasses. Planting of riparian margins with indigenous and ecologically sensitive species provide canopy cover without concentrated leaf fall periods in the autumn, which aids in reducing macrophyte and algae growth, provides a buffer for overland flow run-off, and provides a consistent and appropriate supply of leaf litter resources (food) for the macroinvertebrate community.
- For parts of the Ōtūkaikino River that are highly channelized and undergo routine channel maintenance (such as at Site 9), the addition of meandering sections and changes to these maintenance practices (e.g. minimising or altogether ceasing of channel clearing) may assist in increasing ecosystem health. Meandering sections will increase the diversity of flow regimes and provide a more diverse range of habitats for macroinvertebrate and fish species. Minimising or ceasing channel clearance will reduce disturbances to in-stream fauna.
- Further investigations into the presence of stoneflies, and other clean-water EPT taxa, should be undertaken. This should involve intensive and targeting sampling, particularly of the sites where stoneflies were present in 2012 and 2008. Sampling should be targeted and make best use of live identification processes, rather than preservation of animals. A follow-up monitoring programme may also be justified.
- Minimising intensive land-use change (e.g. urbanisation, intensive farming) in the catchment may assist in maintaining aquatic ecological health.
- Increases to in-stream habitat heterogeneity, especially where there is limited habitat, would assist in enhancing ecological health of the Ōtūkaikino River catchment. The addition of habitats such as maintaining some macrophyte beds, woody debris and logs, leaf packs, and undercut banks, all support a diverse range of macroinvertebrate and fish communities, and are essential for maintaining and improving stream health. Emergent and submerged boulders may also be lacking at many sites, and the addition of these would provide habitat essential for egg-laying substrates for both aquatic insects and fishes.

References

ANZECC (Australian and New Zealand Environment and Conservation Council, ANZECC, and Agriculture and Resource Management Council of Australia and New Zealand, ARMCANZ) (2000). *Australian and New Zealand guidelines for fresh and marine water quality. Volume 1: The guidelines.* ANZECC & ARMCANZ, Artarmon, New South Wales.

Aquatic Ecology (2013). *Fish Values of the Otukaikino River; 2012*, Report prepared by Aquatic Ecology Limited for Christchurch City Council

Clarke K.R. and Warwick R.M. (2001). *Changes in Marine Communities: An Approach to Statistical Analysis and Interpretation*. Version 2. PRIMER-E Ltd, Plymouth, UK.

Environment Canterbury (2011). Waimakariri River Regional Plan. https://www.ecan.govt.nz/your-region/plans-strategies-and-bylaws/waimakariri-river-regional-plan/

Golder Associates (2012). *Canterbury regional urban stream sediment and biofilm quality survey.* Report prepared for Environment Canterbury

EOS Ecology (2012). *Long-term Monitoring if Aquatic Invertebrates: Otukaikino River Catchment 2012*. EOS Ecology Report No. 06064-CCC02-05 prepared for Christchurch City Council

Harding J.S., Clapcott J., Quinn J., Hayes J., Joy M., Storey R., Greig H., Hay J., James T., Beech M., Ozane R., Meredith A. and Boothroyd I. (2009). *Stream habitat assessment protocols for wadeable rivers and streams of New Zealand*. Canterbury Educational Printing Services, University of Canterbury.

Joy M., David B. and Lake M. (2013). *New Zealand freshwater fish sampling protocols. Part 1: wadeable rivers & streams.* Massey University, Palmerston North, New Zealand.

NIWA (National Institute of Water and Atmospheric Research) (2015). *Sediment quality survey for Heathcote River catchment, City Outfall Drain and Estuary Drain*. Report prepared for the Christchurch City Council by NIWA. NIWA Report No. AKL-2015-021.

Peay, K.G., Bruns, T.D., Kennedy, P.G., Bergemann, S.E. & Garbelotto, M. (2007) A strong species-area relationship for eukaryotic soilmicrobes: island size matters for ectomycorrhizal fungi. *Ecology Letters*, 10, 470–480.

Quinn G. and Keough M. (2002). *Experimental Design and Data Analysis for Biologists.* Cambridge University Press, Cambridge, UK.

Stark, J.D & Maxted, J.R. (2007). *A User guide for the Macroinvertebrate Community Index*. Cawthron Institute, Nelson. Report No. 1166 66p.

The R Foundation for Statistical Computing (2013). *The R Foundation for statistical computing.* R version 3.0.2 http://www.r-project.org. [accessed 01 February 2014].

Winterbourn, M.J, Gregson, KLD. & Dolphin, C.H. (2006). *Guide to the Aquatic Insects of New Zealand*. 4th (ed). Entomological Society of New Zealand, Auckland.

Appendix 1: Sediment contaminant concentrations

Hill Laboratories
TRIED, TESTED AND TRUSTED

R J Hill Laboratories Limited
1 Clyde Street Hamilton 3216
Private Bag 3205
Hamilton 3240 New Zealand

T 0508 HILL LAB (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

ANALYSIS REPORT

SPv1

Client:	Boffa Miskell Limited	**Lab No:**	1741836
Contact:	Tanya Blakely	**Date Received:**	16-Mar-2017
	C/- Boffa Miskell Limited	**Date Reported:**	04-May-2017
	PO Box 110	**Quote No:**	83227
	Christchurch 8140	**Order No:**	C17003
		Client Reference:	C17003
		Submitted By:	Tanya Blakely

Sample Type: Sediment

Sample Name:		Site 1 15-Mar-2017 1:00 pm	Site 2 15-Mar-2017 3:30 pm	Site 3 15-Mar-2017 9:40 am	Site 4 16-Mar-2017 9:00 am	Site 5 16-Mar-2017 11:00 am
Lab Number:		1741836.1	1741836.2	1741836.3	1741836.4	1741836.5
Individual Tests						
Fraction >/= 500 µm*	g/100g dry wt	15.9	12.7	11.5	13.0	61.7
Fraction >/= 250 µm*	g/100g dry wt	26.1	23.0	20.4	36.9	76.2
Total Recoverable Copper	mg/kg dry wt	4	11	23	6	6
Total Recoverable Lead	mg/kg dry wt	6.2	23	19.9	10.7	8.4
Total Recoverable Phosphorus	mg/kg dry wt	340	540	590	350	470
Total Recoverable Zinc	mg/kg dry wt	38	63	280	33	46
Total Organic Carbon*	g/100g dry wt	0.38	2.4	1.27	1.17	3.0
7 Grain Sizes Profile						
Dry Matter	g/100g as rcvd	65	48	69	54	66
Fraction >/= 2 mm*	g/100g dry wt	13.3	8.8	7.9	8.7	59.2
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	1.5	1.4	1.2	1.4	1.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	1.2	2.5	2.3	2.9	1.3
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	10.2	10.3	8.9	23.9	14.5
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	36.8	25.6	19.1	35.1	18.3
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	26.6	17.6	10.6	18.0	3.3
Fraction < 63 µm*	g/100g dry wt	10.5	33.9	49.9	10.0	2.2
Haloethers Trace in SVOC Soil Samples by GC-MS						
Bis(2-chloroethoxy) methane	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Bis(2-chloroethyl)ether	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Bis(2-chloroisopropyl)ether	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
4-Bromophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
4-Chlorophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Nitrogen containing compounds Trace in SVOC Soil Samples, GC-MS						
N-Nitrosodiphenylamine + Diphenylamine	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
2,4-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
2,6-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
Nitrobenzene	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
N-Nitrosodi-n-propylamine	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
Aldrin	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
alpha-BHC	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
beta-BHC	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
delta-BHC	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
gamma-BHC (Lindane)	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
4,4'-DDD	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
4,4'-DDE	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10

Sample Type: Sediment						
Sample Name:		Site 1 15-Mar-2017 1:00 pm	Site 2 15-Mar-2017 3:30 pm	Site 3 15-Mar-2017 9:40 am	Site 4 16-Mar-2017 9:00 am	Site 5 16-Mar-2017 11:00 am
Lab Number:		1741836.1	1741836.2	1741836.3	1741836.4	1741836.5
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
4,4'-DDT	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
Dieldrin	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Endosulfan I	mg/kg dry wt	< 0.2	< 0.3	< 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	< 0.3	< 0.2	< 0.2	< 0.2
Endrin	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
Endrin ketone	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
Heptachlor	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Heptachlor epoxide	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Hexachlorobenzene	mg/kg dry wt	< 0.10	< 0.11	< 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	< 0.11	< 0.10	< 0.10	< 0.10
Benzo[b]fluoranthene + Benzo[j] fluoranthene	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Benzo[g,h,i]perylene	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Benzo[k]fluoranthene	mg/kg dry wt	< 0.10	< 0.11	< 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	< 0.11	< 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	< 0.11	< 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
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	< 0.3	< 0.2	< 0.2	< 0.2
2,4,5-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
2,4,6-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.3	< 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	< 0.3	< 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	< 0.3	< 0.2	< 0.2	< 0.2
Dimethylphthalate	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
Di-n-butylphthalate	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
Di-n-octylphthalate	mg/kg dry wt	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS						
1,2-Dichlorobenzene	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
1,3-Dichlorobenzene	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19

Sample Type: Sediment						
Sample Name:		Site 1 15-Mar-2017 1:00 pm	Site 2 15-Mar-2017 3:30 pm	Site 3 15-Mar-2017 9:40 am	Site 4 16-Mar-2017 9:00 am	Site 5 16-Mar-2017 11:00 am
Lab Number:		1741836.1	1741836.2	1741836.3	1741836.4	1741836.5
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS						
1,4-Dichlorobenzene	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
Hexachlorobutadiene	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
Hexachloroethane	mg/kg dry wt	< 0.13	< 0.3	< 0.13	< 0.19	< 0.19
1,2,4-Trichlorobenzene	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Other SVOC Trace in SVOC Soil Samples by GC-MS						
Benzyl alcohol	mg/kg dry wt	< 1.0	< 1.1	< 1.0	< 1.0	< 1.0
Carbazole	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Dibenzofuran	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10
Isophorone	mg/kg dry wt	< 0.10	< 0.11	< 0.10	< 0.10	< 0.10

Sample Name:		Site 7 16-Mar-2017 1:00 pm	Site 9 16-Mar-2017 3:00 pm			
Lab Number:		1741836.6	1741836.7			
Individual Tests						
Fraction >/= 500 µm*	g/100g dry wt	52.6	33.7	-	-	-
Fraction >/= 250 µm*	g/100g dry wt	56.4	48.2	-	-	-
Total Recoverable Copper	mg/kg dry wt	84	4	-	-	-
Total Recoverable Lead	mg/kg dry wt	39	6.1	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	410	390	-	-	-
Total Recoverable Zinc	mg/kg dry wt	46	42	-	-	-
Total Organic Carbon*	g/100g dry wt	2.6	0.94	-	-	-
7 Grain Sizes Profile						
Dry Matter	g/100g as rcvd	38	47	-	-	-
Fraction >/= 2 mm*	g/100g dry wt	50.5	25.3	-	-	-
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.9	4.4	-	-	-
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	1.2	4.0	-	-	-
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	3.8	14.5	-	-	-
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	10.8	40.1	-	-	-
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	16.1	7.9	-	-	-
Fraction < 63 µm*	g/100g dry wt	16.7	3.9	-	-	-
Haloethers Trace in SVOC Soil Samples by GC-MS						
Bis(2-chloroethoxy) methane	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Bis(2-chloroethyl)ether	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Bis(2-chloroisopropyl)ether	mg/kg dry wt	< 0.3	< 0.10	-	-	-
4-Bromophenyl phenyl ether	mg/kg dry wt	< 0.3	< 0.10	-	-	-
4-Chlorophenyl phenyl ether	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Nitrogen containing compounds Trace in SVOC Soil Samples, GC-MS						
N-Nitrosodiphenylamine + Diphenylamine	mg/kg dry wt	< 0.6	< 0.14	-	-	-
2,4-Dinitrotoluene	mg/kg dry wt	< 0.6	< 0.2	-	-	-
2,6-Dinitrotoluene	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Nitrobenzene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
N-Nitrosodi-n-propylamine	mg/kg dry wt	< 0.6	< 0.14	-	-	-
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
Aldrin	mg/kg dry wt	< 0.3	< 0.10	-	-	-
alpha-BHC	mg/kg dry wt	< 0.3	< 0.10	-	-	-
beta-BHC	mg/kg dry wt	< 0.3	< 0.10	-	-	-
delta-BHC	mg/kg dry wt	< 0.3	< 0.10	-	-	-
gamma-BHC (Lindane)	mg/kg dry wt	< 0.3	< 0.10	-	-	-
4,4'-DDD	mg/kg dry wt	< 0.3	< 0.10	-	-	-
4,4'-DDE	mg/kg dry wt	< 0.3	< 0.10	-	-	-
4,4'-DDT	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Dieldrin	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Endosulfan I	mg/kg dry wt	< 0.6	< 0.2	-	-	-

Sample Type: Sediment						
Sample Name:		Site 7 16-Mar-2017 1:00 pm	Site 9 16-Mar-2017 3:00 pm			
Lab Number:		1741836.6	1741836.7			
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
Endosulfan II	mg/kg dry wt	< 0.6	< 0.5	-	-	-
Endosulfan sulphate	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Endrin	mg/kg dry wt	< 0.6	< 0.14	-	-	-
Endrin ketone	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Heptachlor	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Heptachlor epoxide	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Hexachlorobenzene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Polycyclic Aromatic Hydrocarbons Trace in SVOC Soil Samples						
Acenaphthene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Acenaphthylene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Anthracene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Benzo[a]anthracene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Benzo[a]pyrene (BAP)	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Benzo[g,h,i]perylene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Benzo[k]fluoranthene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
1&2-Chloronaphthalene	mg/kg dry wt	< 0.2	< 0.10	-	-	-
Chrysene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Dibenzo[a,h]anthracene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Fluoranthene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Fluorene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Indeno(1,2,3-c,d)pyrene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
2-Methylnaphthalene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Naphthalene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Phenanthrene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Pyrene	mg/kg dry wt	< 0.14	< 0.10	-	-	-
Phenols Trace in SVOC Soil Samples by GC-MS						
4-Chloro-3-methylphenol	mg/kg dry wt	< 0.6	< 0.5	-	-	-
2-Chlorophenol	mg/kg dry wt	< 0.3	< 0.2	-	-	-
2,4-Dichlorophenol	mg/kg dry wt	< 0.3	< 0.2	-	-	-
2,4-Dimethylphenol	mg/kg dry wt	< 0.4	< 0.4	-	-	-
3 & 4-Methylphenol (m- + p-cresol)	mg/kg dry wt	< 0.6	< 0.4	-	-	-
2-Methylphenol (o-Cresol)	mg/kg dry wt	< 0.3	< 0.2	-	-	-
2-Nitrophenol	mg/kg dry wt	< 0.6	< 0.4	-	-	-
Pentachlorophenol (PCP)	mg/kg dry wt	< 6	< 6	-	-	-
Phenol	mg/kg dry wt	< 0.6	< 0.2	-	-	-
2,4,5-Trichlorophenol	mg/kg dry wt	< 0.6	< 0.2	-	-	-
2,4,6-Trichlorophenol	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Plasticisers Trace in SVOC Soil Samples by GC-MS						
Bis(2-ethylhexyl)phthalate	mg/kg dry wt	< 1.1	< 0.5	-	-	-
Butylbenzylphthalate	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Di(2-ethylhexyl)adipate	mg/kg dry wt	< 0.3	< 0.2	-	-	-
Diethylphthalate	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Dimethylphthalate	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Di-n-butylphthalate	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Di-n-octylphthalate	mg/kg dry wt	< 0.6	< 0.2	-	-	-
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS						
1,2-Dichlorobenzene	mg/kg dry wt	< 0.6	< 0.14	-	-	-
1,3-Dichlorobenzene	mg/kg dry wt	< 0.6	< 0.14	-	-	-
1,4-Dichlorobenzene	mg/kg dry wt	< 0.6	< 0.14	-	-	-
Hexachlorobutadiene	mg/kg dry wt	< 0.6	< 0.14	-	-	-
Hexachloroethane	mg/kg dry wt	< 0.6	< 0.14	-	-	-

Sample Type: Sediment						
Sample Name:		Site 7 16-Mar-2017 1:00 pm	Site 9 16-Mar-2017 3:00 pm			
Lab Number:		1741836.6	1741836.7			
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS						
1,2,4-Trichlorobenzene	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Other SVOC Trace in SVOC Soil Samples by GC-MS						
Benzyl alcohol	mg/kg dry wt	< 3	< 1.0	-	-	-
Carbazole	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Dibenzofuran	mg/kg dry wt	< 0.3	< 0.10	-	-	-
Isophorone	mg/kg dry wt	< 0.3	< 0.10	-	-	-

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%.	-	1-7
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	1-7
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-7
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	1-7
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	1-7
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	1-7
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	1-7
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	1-7
7 Grain Sizes Profile*		-	1-7
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	1-7
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	1-7
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	1-7
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	1-7
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	1-7
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	1-7
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	1-7
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-7

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.

This report must not be reproduced, except in full, without the written consent of the signatory.

Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental

Hill Laboratories TRIED, TESTED AND TRUSTED

R J Hill Laboratories Limited
1 Clyde Street Hamilton 3216
Private Bag 3205
Hamilton 3240 New Zealand

T 0508 HILL LAB (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

ANALYSIS REPORT

Client:	Boffa Miskell Limited	**Lab No:**	1742487 SPv1
Contact:	Tanya Blakely	**Date Received:**	17-Mar-2017
	C/- Boffa Miskell Limited	**Date Reported:**	03-May-2017
	PO Box 110	**Quote No:**	83227
	Christchurch 8140	**Order No:**	C17003
		Client Reference:	C17003
		Submitted By:	Tanya Blakely

Sample Type: Sediment

Sample Name:		Site 6 17-Mar-2017 11:00 am	Site 8 17-Mar-2017 9:00 am			
Lab Number:		1742487.1	1742487.2			
Individual Tests						
Fraction >/= 500 µm*	g/100g dry wt	49.8	51.7	-	-	-
Fraction >/= 250 µm*	g/100g dry wt	65.8	59.7	-	-	-
Total Recoverable Copper	mg/kg dry wt	5	10	-	-	-
Total Recoverable Lead	mg/kg dry wt	8.6	11.9	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	470	730	-	-	-
Total Recoverable Zinc	mg/kg dry wt	42	34	-	-	-
Total Organic Carbon*	g/100g dry wt	3.3	7.7	-	-	-
7 Grain Sizes Profile						
Dry Matter	g/100g as rcvd	78	14.9	-	-	-
Fraction >/= 2 mm*	g/100g dry wt	47.9	46.3	-	-	-
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.9	2.6	-	-	-
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	1.1	2.7	-	-	-
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	16.0	8.0	-	-	-
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	23.9	16.6	-	-	-
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	7.9	9.0	-	-	-
Fraction < 63 µm*	g/100g dry wt	2.3	14.7	-	-	-
Haloethers Trace in SVOC Soil Samples by GC-MS						
Bis(2-chloroethoxy) methane	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Bis(2-chloroethyl)ether	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Bis(2-chloroisopropyl)ether	mg/kg dry wt	< 0.10	< 0.4	-	-	-
4-Bromophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.4	-	-	-
4-Chlorophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Nitrogen containing compounds Trace in SVOC Soil Samples, GC-MS						
N-Nitrosodiphenylamine + Diphenylamine	mg/kg dry wt	< 0.18	< 0.7	-	-	-
2,4-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.7	-	-	-
2,6-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Nitrobenzene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
N-Nitrosodi-n-propylamine	mg/kg dry wt	< 0.18	< 0.7	-	-	-
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
Aldrin	mg/kg dry wt	< 0.10	< 0.4	-	-	-
alpha-BHC	mg/kg dry wt	< 0.10	< 0.4	-	-	-
beta-BHC	mg/kg dry wt	< 0.10	< 0.4	-	-	-
delta-BHC	mg/kg dry wt	< 0.10	< 0.4	-	-	-
gamma-BHC (Lindane)	mg/kg dry wt	< 0.10	< 0.4	-	-	-
4,4'-DDD	mg/kg dry wt	< 0.10	< 0.4	-	-	-
4,4'-DDE	mg/kg dry wt	< 0.10	< 0.4	-	-	-

Sample Type: Sediment						
Sample Name:		Site 6 17-Mar-2017 11:00 am	Site 8 17-Mar-2017 9:00 am			
Lab Number:		1742487.1	1742487.2			
Organochlorine Pesticides Trace in SVOC Soil Samples by GC-MS						
4,4'-DDT	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Dieldrin	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Endosulfan I	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Endosulfan II	mg/kg dry wt	< 0.5	< 0.7	-	-	-
Endosulfan sulphate	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Endrin	mg/kg dry wt	< 0.18	< 0.7	-	-	-
Endrin ketone	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Heptachlor	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Heptachlor epoxide	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Hexachlorobenzene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Polycyclic Aromatic Hydrocarbons Trace in SVOC Soil Samples						
Acenaphthene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Acenaphthylene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Anthracene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Benzo[a]anthracene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Benzo[a]pyrene (BAP)	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Benzo[g,h,i]perylene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Benzo[k]fluoranthene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
1&2-Chloronaphthalene	mg/kg dry wt	< 0.10	< 0.3	-	-	-
Chrysene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Dibenzo[a,h]anthracene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
Fluoranthene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Fluorene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Indeno(1,2,3-c,d)pyrene	mg/kg dry wt	< 0.10	< 0.4	-	-	-
2-Methylnaphthalene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Naphthalene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Phenanthrene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Pyrene	mg/kg dry wt	< 0.10	< 0.17	-	-	-
Phenols Trace in SVOC Soil Samples by GC-MS						
4-Chloro-3-methylphenol	mg/kg dry wt	< 0.5	< 0.7	-	-	-
2-Chlorophenol	mg/kg dry wt	< 0.2	< 0.4	-	-	-
2,4-Dichlorophenol	mg/kg dry wt	< 0.2	< 0.4	-	-	-
2,4-Dimethylphenol	mg/kg dry wt	< 0.4	< 0.4	-	-	-
3 & 4-Methylphenol (m- + p-cresol)	mg/kg dry wt	< 0.4	< 0.7	-	-	-
2-Methylphenol (o-Cresol)	mg/kg dry wt	< 0.2	< 0.4	-	-	-
2-Nitrophenol	mg/kg dry wt	< 0.4	< 0.7	-	-	-
Pentachlorophenol (PCP)	mg/kg dry wt	< 6	< 7	-	-	-
Phenol	mg/kg dry wt	< 0.2	< 0.7	-	-	-
2,4,5-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.7	-	-	-
2,4,6-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Plasticisers Trace in SVOC Soil Samples by GC-MS						
Bis(2-ethylhexyl)phthalate	mg/kg dry wt	< 0.5	< 1.4	-	-	-
Butylbenzylphthalate	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Di(2-ethylhexyl)adipate	mg/kg dry wt	< 0.2	< 0.4	-	-	-
Diethylphthalate	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Dimethylphthalate	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Di-n-butylphthalate	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Di-n-octylphthalate	mg/kg dry wt	< 0.2	< 0.7	-	-	-
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS						
1,2-Dichlorobenzene	mg/kg dry wt	< 0.18	< 0.7	-	-	-
1,3-Dichlorobenzene	mg/kg dry wt	< 0.18	< 0.7	-	-	-

Sample Type: Sediment					
Sample Name:	Site 6 17-Mar-2017 11:00 am	Site 8 17-Mar-2017 9:00 am			
Lab Number:	1742487.1	1742487.2			
Other Halogenated compounds Trace in SVOC Soil Samples by GC-MS					
1,4-Dichlorobenzene mg/kg dry wt	< 0.18	< 0.7	-	-	-
Hexachlorobutadiene mg/kg dry wt	< 0.18	< 0.7	-	-	-
Hexachloroethane mg/kg dry wt	< 0.18	< 0.7	-	-	-
1,2,4-Trichlorobenzene mg/kg dry wt	< 0.10	< 0.4	-	-	-
Other SVOC Trace in SVOC Soil Samples by GC-MS					
Benzyl alcohol mg/kg dry wt	< 1.0	< 4	-	-	-
Carbazole mg/kg dry wt	< 0.10	< 0.4	-	-	-
Dibenzofuran mg/kg dry wt	< 0.10	< 0.4	-	-	-
Isophorone mg/kg dry wt	< 0.10	< 0.4	-	-	-

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%.	-	1-2
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	1-2
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-2
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	1-2
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	1-2
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	1-2
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	1-2
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	1-2
7 Grain Sizes Profile*		-	1-2
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	1-2
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	1-2
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	1-2
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	1-2
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	1-2
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	1-2
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	1-2
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-2

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.

This report must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Appendix 2: SIMPER Results

SIMPER
Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: Data1
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90.00%

Factor Groups

Sample	Year
1	2017
2	2017
3	2017
4	2017
5	2017
6	2017
7	2017
8	2017
9	2017
1	2012
2	2012
3	2012
4	2012
5	2012
6	2012
7	2012
8	2012
9	2012

Group 2017
Average similarity: 44.37

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pycnocentria	979.33	17.77	2.28	40.06	40.06
Potamopyrgus	510.00	9.40	2.01	21.19	61.25
Deleatidium	226.78	3.88	1.09	8.74	69.99
Pycnocentrodes	171.11	3.13	1.07	7.07	77.06
Hydropsyche-Aoteapsyche	130.89	2.55	1.13	5.76	82.81
Orthocladiinae	122.67	1.86	0.82	4.19	87.00
Ostracoda	673.22	1.08	0.45	2.44	89.44
Oxyethira	84.00	0.84	0.96	1.90	91.34

Group 2012
Average similarity: 50.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Potamopyrgus	946.89	16.87	1.47	33.62	33.62
Pycnocentrodes	466.44	8.71	2.19	17.36	50.98
Pycnocentria	404.56	6.81	1.63	13.58	64.56

Deleatidium	228.78	4.20	1.08	8.38	72.94
Ostracoda	110.52	2.38	1.38	4.75	77.69
Hydropsyche-Aoteapsyche	215.56	2.00	0.88	3.98	81.67
Orthocladiinae	176.59	1.95	1.71	3.89	85.56
Physella	149.44	1.36	1.04	2.71	88.27
Paracalliope	115.19	1.11	0.45	2.22	90.49

Groups 2017 & 2012
Average dissimilarity = 57.02

Species	Group 2017 Av.Abund	Group 2012 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Pycnocentria	979.33	404.56	9.86	1.10	17.29	17.29
Potamopyrgus	510.00	946.89	9.78	1.30	17.15	34.43
Ostracoda	673.22	110.52	7.80	0.50	13.67	48.11
Pycnocentrodes	171.11	466.44	4.82	1.42	8.46	56.56
Deleatidium	226.78	228.78	3.08	1.30	5.41	61.97
Hydropsyche-Aoteapsyche	130.89	215.56	2.76	1.19	4.85	66.82
Orthocladiinae	122.67	176.59	2.49	0.87	4.36	71.18
Paracalliope	0.33	115.19	2.08	0.68	3.65	74.83
Physella	52.33	149.44	1.92	0.73	3.37	78.20
Oxyethira	84.00	96.11	1.63	0.92	2.85	81.05
Hudsonema amabile	46.78	86.04	1.55	0.76	2.72	83.77
Elmidae	79.22	42.85	1.43	0.87	2.50	86.27
Helicopsyche	7.33	56.04	0.94	0.67	1.66	87.93
Tanytarsini	12.11	66.89	0.89	0.55	1.56	89.49
Oligochaeta	48.00	53.26	0.79	1.07	1.38	90.87