Dunbar, Days & Henderson Waterways

Aquatic Ecology Technical Report
Prepared for Christchurch City Council

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Cover photograph: Henderson Waterway, upstream of Sparks Road. Boffa Miskell 2016

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Executive summary

The Christchurch City Council (CCC) commissioned Boffa Miskell Limited to conduct an aquatic ecology survey of eight sites located in Dunbar, Days, Hendersons Road Branch, and Henderson Waterways, in the upper Cashmere Stream catchment. The CCC is considering realignment and enhancement of these highly incised, channelized, human-made "farm drains". This report describes the results of an aquatic ecology survey of these waterways, which may be used as baseline information to inform water enhancement design considerations, and for comparison to post-naturalisation conditions, to determine the success of the realignment and enhancement activities.

Basic water-quality parameters of pH, dissolved oxygen, conductivity, and temperature were generally within ranges expected in a spring-fed rural environment, during base-flow conditions. Riparian conditions were poor, with little riparian vegetation (other than rank grass, hawthorn and gorse, scattered willows, and occasional poplar shelterbelts) and a general lack of canopy cover and in-stream shading. In-stream conditions were similarly poor, with generally homogeneous flow and habitat conditions, and little cover available for aquatic species.

The macroinvertebrate communities were dominated by taxa typical of lowland agricultural waterways, with only a few representatives from the pollution-sensitive or "clean-water" EPT taxa (i.e. caddisflies) present, and generally representative of poor quality aquatic habitat present. However, a kēkēwai (freshwater crayfish) was found in the lower reaches of Henderson Waterway and kākahi (freshwater mussel) were found nearby this same site. We note that CCC contractors have also observed kēkēwai in the lower reaches of Dunbar Waterway, near to its confluence with Cashmere Stream. Kēkēwai and kākahi are of conservation interest due to their status of "at risk, declining".

The freshwater fish community was also depauperate, with species richness generally low. Five species was the most recorded at any site. The fish species encountered included two species of conservation interest; inanga and longfin eel, both of which are listed as "at risk, declining". Moreover, over 30 longfin eels were captured from the lower reaches of Henderson Waterway, at the same site where a kēkēwai found, and kākahi were found downstream.

We make a number of recommendations to consider when developing future realignment and enhancement activities for these waterways, including actions to improve habitat for a diversity of aquatic fauna and generally improving in-stream health.

Recommendations include:

- Best practice stormwater treatment for future development in the catchment;
- Removal of timber-lined channels and regrading of banks to reform natural, gently-graded bank profiles
- Realignment of waterways to include sinuosity;
- In-bank and in-stream habitat for fauna;
- Improving the variety of flow (e.g. pools and riffles) and habitat availability (boulders, log jams, stable undercut banks);
- Adapting current macrophyte and maintenance practices;
- Planting of riparian vegetation including a variety of ecologically sensitive indigenous species;
- Use 'softer' rehabilitation / restoration methods, which might involve leaving sites known to support populations of less mobile taxa, such as kēkēwai and kākahi, relatively intact;
- Development of a programme to salvage freshwater fauna prior to realignment works;

- Carry out focussed surveys for kēkēwai and kākahi prior to realignment works to better understand where 'source' populations may occur and need to be protected;
- Aim for no net loss of freshwater habitat as a result of the realignment and naturalisation programme; and
- Development of a monitoring programme to assess restoration success.

Introduction

Dunbar, Days, Hendersons Road Branch, and Henderson Waterways flow in a south-east direction from Aidenfield and into Cashmere Stream and Ōpāwaho / the Heathcote River. The waterways flow predominantly through mixed-use agricultural land, receiving stormwater discharges from residential subdivisions in Aidanfield and Halswell, as well as runoff from the surrounding farmland.

Historically, the area would have been a mosaic of slow-flowing lowland streams meandering through wetlands and swamps. But the upper Cashmere Stream catchment has been extensively modified, with human-made drains converting the wetlands to agricultural and urban lands.

Dunbar, Days, Hendersons Road Branch, and Henderson Waterways are highly incised and channelized, human-made “farm drains”. The Christchurch City Council (CCC) is proposing the realignment and enhancement of these waterways under the Council’s stormwater projects.

This report describes the results of an aquatic ecology survey of these waterways, which may be used as baseline information to inform waterway enhancement design, and for comparison to post-naturalisation conditions, to determine the success of the realignment and enhancement activities.

Scope

The CCC commissioned Boffa Miskell to conduct an aquatic ecology survey of eight sites within waterways in the upper Cashmere Stream catchment: Dunbar, Days, Hendersons Road Branch, and Henderson Waterways.

This survey was designed to assess the existing ecological health and values, and to inform the potential realignment and enhancement, of these waterways.

The surveys included:

- Conducting the full CREAS (Christchurch River Environment Assessment Survey), repeated at 50 m locations along the full extent of all the waterways;
- Describing the current ecological condition of these waterways, including riparian and in-stream habitat conditions, and the macroinvertebrate and fish communities;
- Discussing overall ecological health of the sites; and
- Making recommendations on how to improve the health and to inform the potential realignment and enhancement works.

Methods

Site locations

The CCC provided Boffa Miskell with approximate locations for 8 sites located for surveying. Table 1 shows the site names and numbers and northing and easting co-ordinates.

Table 1. Freshwater ecology survey sites within Henderson, Dunbar, and Days waterways surveyed in October and November 2016.

Site number	Site name	Easting	Northing
S1	Dunbar Waterway (upstream)	2475983	5737088
S2	Dunbar Waterway (downstream)	2477048	5736481
S3	Days Waterway (upstream)	2475971	5737689
S4	Days Waterway (downstream)	2476505	5737474
S5	Henderson Road Branch Waterway	2476745	5737704
S6	Henderson Waterway (upstream)	2476832	5737489
S7	Henderson Waterway (mid)	2477050	5737224
S8	Henderson Waterway (downstream)	2477502	5736673

The co-ordinates (northing and easting) of each site (as provided in the map 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 8 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 (i.e. no less than 5-7 days after a flood peak). All methods were in line with that detailed in the CCC Waterway Ecology Standard Sampling Methodology.

The CREAS methodology, as described by McMurtrie and Suren (2008), was used to assess riparian and in-stream habitat conditions, at 50 m intervals, along the length of Dunbar, Days, Hendersons Road Branch, and Henderson Waterways. Full results of the CREAS has not been provided in this report, however, the information gained during this part of the project has been summarised to report on the:

- Extent of perennial flow;
- Presence of springs; and
- Presence of potential or actual barriers to in-stream fish passage.

The CREAS for all waterways and the habitat assessments and surveying of the macroinvertebrate community were conducted between 27 October and 14 November 2016. Basic water quality measures and the fish community were surveyed between 18 and 22 November 2016.

Figure 1. Locations of the eight sites in Dunbar, Days, Hendersons Road Branch, and Henderson Waterways, surveyed in October and November 2016.

Habitat conditions

Firstly, the CREAS method was conducted (see McMurtrie and Suren 2008 for methodology), which involved walking the length of each of the waterways, from downstream to upstream. A variety of riparian and in-stream parameters (at sites located at 50 m intervals) were measured as well as noting the presence of springs, the extent of perennial flow, barriers to in-stream passage, and any other information important for consideration in the naturalisation of these waterways.

The full aquatic ecology surveys were then conducted at each of the eight previously selected sites.

At each site, habitat and macroinvertebrates were assessed within a 20 m reach. The fish community was then assessed within an at least 30 m reach and 30 m^2 area, and included the habitat and macroinvertebrate reach surveyed previously. The fish community was surveyed at least three days after habitat and macroinvertebrate community assessments were made.

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

Dunbar, Days, Hendersons Road Branch, and Henderson Waterways are spring-fed tributaries of Cashmere Stream, and may be classified as spring-fed – plains waterways under Environment Canterbury's Land and Water Regional Plan (LWRP). However, in order to be consistent with the CCC's Comprehensive Stormwater Network Discharge Consent for Ōtautahi / Christchurch City and Te Pātaka o Rakaihautū / Banks Peninsula, all waterways surveyed in this study were compared against the LWRP's freshwater outcomes and guidelines for Banks Peninsula streams.

Water quality

At each site, spot measures of specific conductivity, pH, dissolved oxygen, and water temperature were taken using handheld meters (TPS WP81 conductivity / pH meter; TPS WP82Y dissolved oxygen meter). These parameters were measured immediately before the fish survey, in late November 2016.

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

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

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

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

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

Riparian and in-stream habitat

Total wetted width (m) was also recorded at each of the three transects. An average wetted width was calculated from these three measures 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 the three transects at each site.

At each of five locations (TL bank, 25%, 50%, 75%, and TR bank) along each of the three transects, at each site, the following parameters were also measured:

- Water depth (cm);
- Soft sediment depth (cm);
- Embeddedness (%);
- Substrate composition (%);
- Macrophyte depth (cm), percent cover, type (submerged or emergent), and dominant species present;
- Percent cover and type of organic material (leaves, moss, coarse woody debris); and
- Percent cover and type of periphyton.

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).

Macroinvertebrate community

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

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

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

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

Fish community

The fish community was surveyed[1] within a (minimum) reach of 30 m in length and 30m^2 in area. This area overlapped with the 20 m reach where the macroinvertebrate community and habitat assessments were made. However, the habitat and macroinvertebrate assessments were conducted at least three days prior to the fish survey.

Survey reaches at each site (with the exception of Site 7 – Henderson Waterway, mid) were divided into many subsections of approximately 2-3 m in length and electro-fished using a single pass with a Kainga EFM 300 backpack mounted electro-fishing machine (NIWA Instrument Systems, Christchurch). Fish were captured in a downstream push net or in a hand (dip) net and temporarily held in buckets. All fish were then identified, counted and measured (fork length, mm) before being returned alive to the stream. The electric fishing surveys were conducted on 18 or 22 November 2016.

Macrophyte cover (primarily the exotic curly pondweed, *Potamogeton crispus*) was extremely high at Henderson Waterway sites 7 (>90% cover) and 8 (>70% cover) on 22 November 2016. Capturing fish using electric fishing was difficult at site 8 and deemed ineffective at site 7. Therefore, the fish community at these two sites was surveyed using a combination of baited fyke nets and Gee minnow traps. Note, electric fishing techniques were also used at site 8.

At each site, two fyke nets (baited with tinned cat food), and five Gee minnow traps[2] (baited with Marmite and cat biscuits) were set within a 30 m survey reach late in the afternoon (22 November 2016) and left overnight. The following morning (23 November 2016), 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.

[2] Gee minnow traps mesh size, 1/8 inch or 3.175 mm; fyke nets mesh size, 4 mm. Fyke net dimensions were in-line with recommendations of Joy et al. (2013).

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.

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) (soft bottom)** – this index is based on tolerance scores for individual macroinvertebrate taxa found in 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 2 provides a summary of how MCI scores were used to evaluate stream health.
- **Quantitative Macroinvertebrate Community Index (QMCI) (soft bottom)** – this is a variant of the MCI, which instead uses abundance data. The QMCI provides information about the dominance of pollution-sensitive species in soft-bottomed streams. Table 2 provides a summary of how QMCI scores were used to evaluate stream health.

Table 2. Interpretation of MCI and QMCI scores for 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 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.

Differences in macroinvertebrate community

Differences in total abundance, taxonomic richness, EPT richness, and MCI and QMCI values calculated for each of the eight sites were graphically compared. Statistical analyses were not conducted as there was no replication within sites.

A non-metric multidimensional scaling (or NMDS) ordination[3], with 1000 random permutations, of abundance data was used to determine if the macroinvertebrate community found was similar among the waterways (Dunbar, Days, Hendersons Road Branch, and Henderson).

NMDS ordinations rank sites such that distance in ordination space represents community dissimilarity (in this case using the Bray-Curtis metric). Therefore, an ordination score (an *x* and a *y* value) for the entire macroinvertebrate community found at a 'site' can be presented on an *x*-*y* scatterplot to graphically show how similar (or dissimilar) the community was between 2011

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

and 2016. Ordination scores that are closest together are more similar in macroinvertebrate community composition, than those further apart (Quinn and Keough 2002).

An analysis of similarities (ANOSIM), with 100 permutations, was then used to test for significant differences in macroinvertebrate community composition among waterways. 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, waterways could be quite distinct from one another in ordination space), but ANOSIM results show whether these differences are in fact statistically significantly different[4].

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

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

Fish community

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

Results

Habitat conditions

Specific conductivity

Conductivity, which is often used to indicate the level of pollutants in the water column, was generally high at all eight sites. Measures ranged from 154 µS / cm at Site 1: Dunbar Waterway and 398 µS / cm at Site 8: Henderson Waterway (Figure 2). The three sites along Henderson Waterway, as well as Henderson Road Drain Branch and the downstream most site on Days Waterway, had the highest recorded conductivities.

The conductivities were similar to those recorded in many degraded urban systems, and generally similar to those recorded in sites within the Heathcote River and Halswell River catchments in 2015 and 2016, respectively (Blakely 2015, 2016), but slightly higher than conductivities recorded in the Avon River catchment in 2013 (Blakely 2014).

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

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

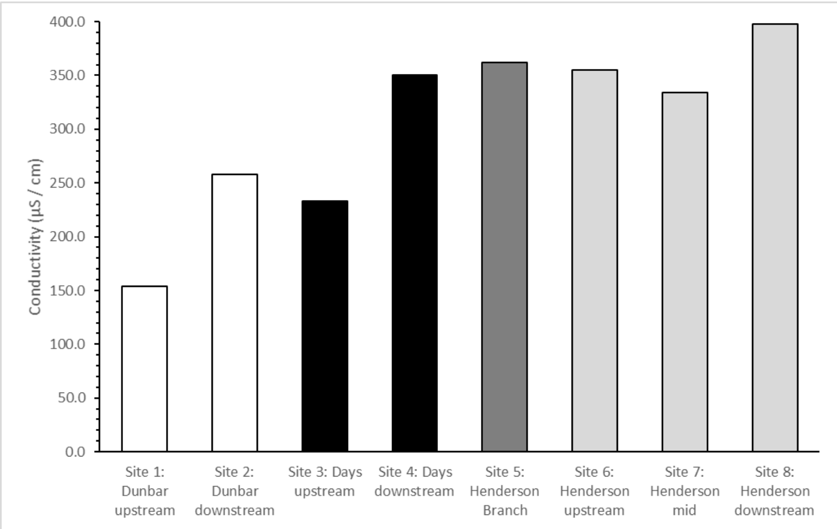


Figure 2. Specific conductivity measured, on one occasion, at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

pH

pH was generally similar across sites, with circum-neutral pH recorded in all sites except for Site 3: Days Waterway and Site 6: Henderson Waterway, which were found to be more alkaline (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, for all sites except Site 3 and Site 6. However, it's important to note that pH can fluctuate both daily and seasonally, particularly at sites with high macrophyte and periphyton cover.

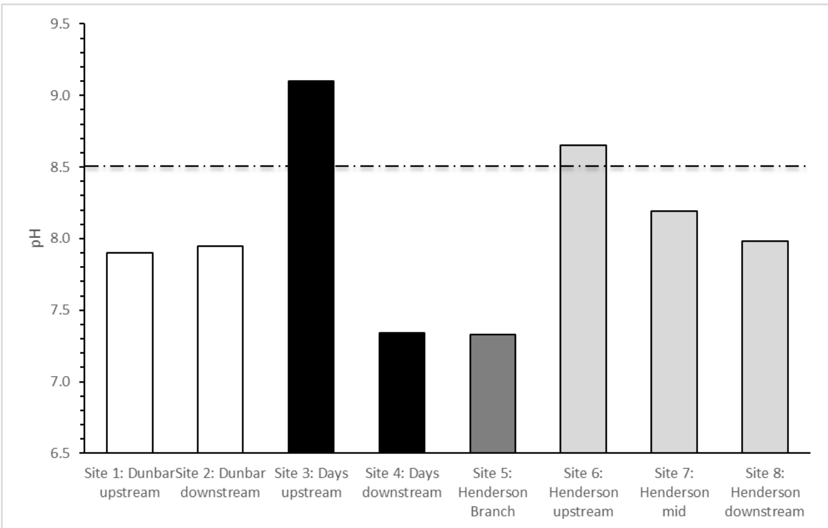


Figure 3. pH measured, on one occasion, at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars. The area below the black dashed line meets Canterbury's Land and Water Regional Plan (LWRP) recommended water quality standard for receiving waters of pH between 6.5 and 8.5.

Dissolved oxygen

Dissolved oxygen (DO, %) was variable across sites, with particularly low DO recorded in Site 1: Dunbar Waterway and Site 4: Days Waterway (Figure 4). The spot measure of DO at Site 4: Days Waterway – downstream and Site 1: Dunbar Waterway – upstream fell below the LWRP's recommended water quality standard of 90% for Banks Peninsula waterways.

All of these waterways surveyed are spring-fed systems and as such may be better compared the LWRP's guidelines for spring-fed – plains waterways. Only Site 4: Days Waterway – downstream was found to be lower than the 70% (minimum) standard for spring-fed – plains waterways.

It is important to note, however, that both Dunbar and Days Waterways had very low water levels at the time of sampling (i.e. at the end of November 2016).

Moreover, DO was very high at some sites and was likely to have been influenced by high macrophyte and / or algal cover[6].

It's important to note that DO was measured only once during the daytime, and at different times of the day across the eight sites. DO can vary diurnally and seasonally[7].

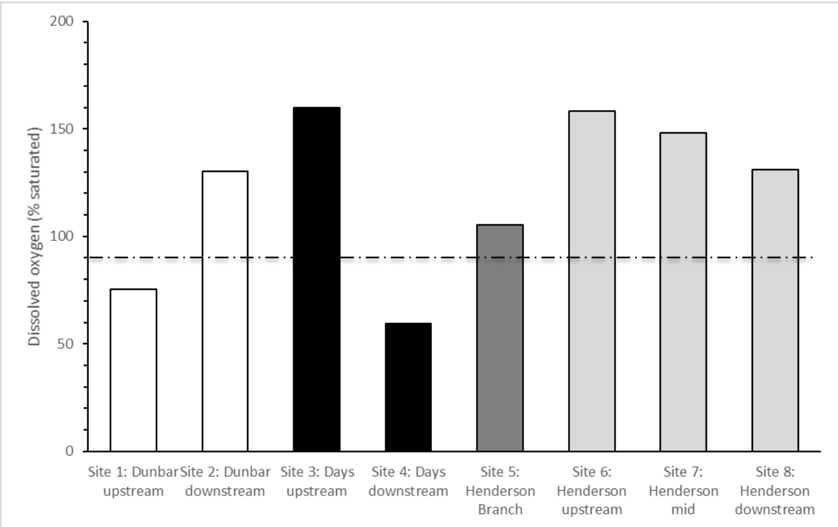


Figure 4. Dissolved oxygen (DO) measured, on one occasion, at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars. The area above the black dashed line meets Canterbury's Land and Water Regional Plan (LWRP) recommended water quality standard of DO above 90% saturation for Banks Peninsula waterways.

[6] Aquatic plants release oxygen into the water during photosynthesis, and can dramatically influence dissolved oxygen levels during the day time.

[7] Large daily fluctuations in DO are characteristic of bodies of water with extensive plant or algal growth. DO levels rise from morning through to the afternoon as plants photosynthesize, releasing oxygen into the water. Oxygen is then taken up by plants during respiration during hours of darkness / low light

Water temperature

Water temperature was variable across sites, but with temperatures at all sites below the LWRP guideline of 20°C for Canterbury Rivers (Figure 5). The coolest water temperatures of approximately 14.5 °C were recorded at Site 2: Dunbar Waterway and Site 5: Hendersons Road Branch Drain. Site 1: Dunbar Waterway, Site 7: Henderson Waterway, and Site 8: Henderson Waterway had the highest recorded water temperatures (19.1 - 20°C). Water temperatures recorded in the eight sites surveyed in this study were generally similar to those recorded in the Avon, Heathcote, and Halswell River catchments in 2013, 2015, and 2016, respectively (Blakely 2014, 2015, 2016). It is important to note that water temperature, which can vary diurnally and seasonally, was measured only once during the daytime, and at different times of the day across the eight sites.

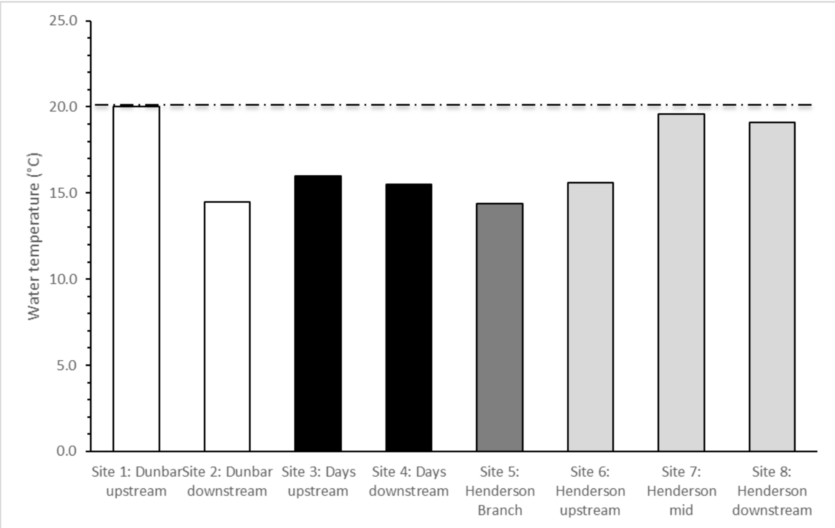


Figure 5. Water temperature measured, on one occasion, at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars. The area below the black dashed line meets Canterbury's Land and Water Regional Plan (LWRP) recommended water quality standard of water temperature below 20 °C for Canterbury Rivers.

Velocity

Water velocity was generally slow at all sites, with the fastest velocity recorded in Site 8: Henderson Waterway, while Site 2: Dunbar Waterway and Site 4: Days Waterway had very little flow (i.e. it was not measurable with a flow meter, so recorded as 0) (Figure 6).

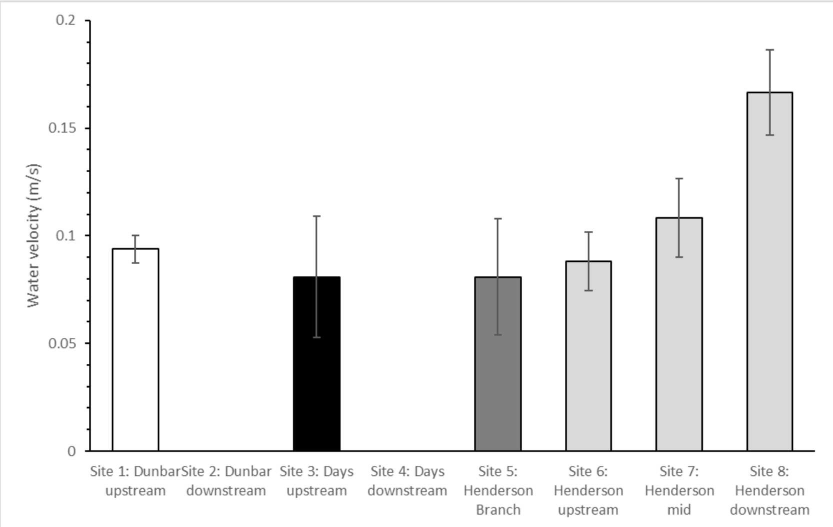


Figure 6. Mean (±1SE, n = 3) velocity (m / s) measured once at each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

Riparian and in-stream habitat

A brief summary of the general habitat conditions encountered at each site is given in Table 3; further site descriptions are provided below.

Table 3. Summary of the riparian and in-stream habitat conditions at each of the five sites surveyed between 21 and 23 March 2016. TLB = true left bank; TRB = true right bank.

	Surrounding land use	**Bank material**	**Canopy cover**	**Vegetated ground cover**	**Horizontal bank undercut**	**Overhanging vegetation**	**Flow habitat type (%still:backwater: pool:run:riffle)**	**Dominant substrate type**
Site 1: Dunbar Waterway - upstream	TLB: Rural TRB: Rural	TLB: Earth TRB: Earth	TLB: 13% TRB: 0%	TLB: 90% TRB: 90%	TLB: 15 cm TRB: 0 cm	TLB: 5 cm TRB: 5 cm	90:0:0:10:0	Silt/ sand
Site 2: Dunbar Waterway - downstream	TLB: Rural TRB: Rural	TLB: Earth TRB: Earth	TLB: 15% TRB: 3%	TLB: 80% TRB: 100%	TLB: 5 cm TRB: 5 cm	TLB: 1 cm TRB: 2 cm	100:0:0:0:0	Silt/ sand
Site 3: Days Waterway - upstream	TLB: Rural TRB: Rural	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 100% TRB: 80%	TLB: 0 cm TRB: 0 cm	TLB: 0 cm TRB: 0 cm	40:0:0:60:0	Silt/ sand
Site 4: Days Waterway - downstream	TLB: Rural TRB: Rural	TLB: Earth TRB: Earth	TLB: 0% TRB: 0%	TLB: 33% TRB: 90%	TLB: 76 cm TRB: 100 cm	TLB: 10 cm TRB: 13 cm	20:0:0:80:0	Silt/ sand
Site 5: Hendersons Road Drain Branch	TLB: Residential TRB: Residential	TLB: Wood TRB: Wood	TLB: 50% TRB: 3%	TLB: 0% TRB: 0%	TLB: 2 cm TRB: 0 cm	TLB: 0 cm TRB: 0 cm	60:0:0:40:0	Silt/ sand
Site 6: Henderson Waterway - upstream	TLB: Residential TRB: Rural	TLB: Wood TRB: Wood	TLB: 1% TRB: 0%	TLB: 0% TRB: 0%	TLB: 0 cm TRB: 0 cm	TLB: 0 cm TRB: 0 cm	20:0:0:80:0	Silt/ sand
Site 7: Henderson Waterway - mid	TLB: Road, residential TRB: Rural	TLB: Earth TRB: Earth	TLB: 0% TRB: 5%	TLB: 100% TRB: 72%	TLB: 0 cm TRB: 3 cm	TLB: 2 cm TRB: 6 cm	20:0:0:60:20	Silt/ sand
Site 8: Henderson Waterway - downstream	TLB: Road, residential TRB: Rural	TLB: Earth TRB: Earth	TLB: 0% TRB: 27%	TLB: 100% TRB: 67%	TLB: 0 cm TRB: 5 cm	TLB: 1 cm TRB: 10 cm	20:0:0:80:20	Silt/ sand

General site descriptions

The descriptions and photographs below are based on the habitat assessment conducted in October 2016. When the sites were revisited to assess the fish community in November 2016, macrophyte and periphyton cover was markedly higher than in October 2016. Additional site photos of each site were taken in November 2016. These are shown in Appendix 1.

The adjacent land use for all of the waterways surveyed in this study was rural / agricultural and farming with some residential use. The extent of residential development surrounding the largely rural waterways, and individual sites, can be seen in Figure 1.

Dunbar Waterway flows from Halswell Road joining Cashmere Stream some 2 km downstream of its headwater stormwater wetlands. The waterway is located in mixed-use rural farmland and is fenced along much of its length. The substrate within the waterway was largely dominated by soft sediments, over what appeared to be a hard (likely clay) base. Gravels and cobbles were generally absent along the length of the waterway.

It appears to be permanently wet for the entire extent of its alignment, and is likely to have surface water at all times of the year. However, water depth was observed to be very low in the upper reaches of Dunbar Waterway.

Three perched culverts were found along Dunbar Waterway (A2, A3, and A4; Appendix 2).

The first was a perched culvert located approximately 120 m upstream of Site 1 (A2; Appendix 2). The other perched culverts were located around Sparks Road: one at Sparks Road (A3) and another approximately 60 m downstream of Sparks Road (A4). The perched nature of all of these culverts will likely present an obstacle to the in-stream movement of migratory fish species (and possibly also kēkēwai), particularly those with poor climbing abilities, such as inanga.

Days Waterway also flows from Halswell Road, through mixed-use rural farmland, and into Henderson Waterway approximately 1.2 km downstream. The waterway is only partially fenced, with stock access to the waterway possible along much of its length.

This waterway had surface water present along its entire length when assessed in October 2016. However, when individual sites were revisited for the fish survey in November 2016, water depth and wetted width appeared to be much lower. It is possible, therefore, that upstream reaches of Days Waterway are not perennial, and may dry during the summer months when rainfall events are relatively infrequent.

A potential barrier to fish (and other aquatic fauna) passage was found approximately 150 m downstream of Site 4 (P3; Appendix 2). The concrete lining along the bottom of the channel has eroded underneath, and may be perched and impassable for some aquatic fauna, particularly during low flow conditions.

Hendersons Road Branch Waterway is a short, timber-lined waterway flowing through a residential area for approximately 250 m before joining Henderson Waterway.

This waterway was flowing along its entire extent when assessed in October 2016.

Two potential barriers to fish (and other aquatic fauna) passage were noted along Hendersons Road Branch Waterway (P1, P2; Appendix 2).

The upstream most potential obstacle (P1) was due to a debris gate, which did not reach all the way to the stream bed, but had the potential to hold back woody debris and block water flow and the channel (P1; Appendix 2). This was located approximately 150 m upstream of Site 3, and in the upper most reaches of Hendersons Road Branch Waterway.

The second potential barrier to in-stream movement (migration) was located at / near Site 2. Timber cross beams lined the stream bed, supporting the timber-lined channel. These had the potential to become perched, and impassable to some species, particularly during low flow conditions (P2; Appendix 2).

Henderson Waterway starts around 800 m downstream of Halswell Road, collecting water from Days Waterway and Hendersons Road Drain Branch and eventually discharging into Cashmere Stream. The upper 360 m of Henderson Waterway is a timber-lined channel, with Hendersons Road and residential housing on the true right and rural mixed-use farmland on the true left. From Sparks Road downstream to its confluence with Cashmere Stream, Henderson Waterway is unlined, with earth banks, flowing through rural land (Figure 1).

Henderson Waterway contained surface water, flowing in places, along its entire extent when assessed in October 2016.

One actual and two potential in-stream barriers were noted during the CREAS work (A1, P4, P5; Appendix 2).

A1 was located approximately 150 m upstream of Site 6, at the upper most end of the waterway. Here the culvert was perched during baseflow conditions, and would likely present an obstacle to most migratory fish species, and potentially to kēkēwai. Poor climbing species, such as inanga will almost certainly be unable to navigate through this culvert, and a number of inanga were observed in the pool immediately downstream of this structure.

P4, the culvert under Sparks Road and particularly the upstream end, was noted as a potential barrier during low flow conditions and as a result of blockages by debris and litter (Appendix 2).

P5 was a culvert under a farm crossing of Henderson Waterway, just upstream of Site 7. This was noted as having the potential to be perched during low flows, and may also be impassable to some fish species during high flows (due to velocity barrier within the culvert) (Appendix 2).

Site 1: Dunbar Waterway - upstream

Site 1 was the upstream most site located on Dunbar Waterway, approximately 600 m downstream of Halswell Road (Figure 1). Here the waterway was highly channelized / straightened and incised, with grassed earth banks and a poplar shelter belt along the true left bank. Both banks were fenced, excluding stock from accessing the waterway. The waterway at Site 1 was approximately 1 m wide and relatively shallow, with an average water depth of 5 cm. The velocity on the day of sampling was 0.09 m / s.

The wetted width and water depth was visibly lower, and flow was virtually absent, when the site was revisited for the fish survey in November 2016. The stream bed was dominated by fine substrates, with a thick (average depth of 14 cm) layer of silt / sand present, and an average Substrate Index of 3.0.

Undercut banks and overhanging vegetation were largely absent at the site. Canopy cover was generally low at the site (Table 3), however, rank grass and a poplar shelterbelt (on the true left bank) provided in-stream shading at times of the day. Macrophyte and algal growth was limited at the site (Photo 1), presumably, in part, as a result of the shading provided by the shelterbelt.

Photo 1. Site 1: Dunbar Waterway – upstream, located approximately 600 m downstream of Halswell Road, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 2: Dunbar Waterway - downstream

Site 2 was located on Dunbar Waterway approximately 1.3 km downstream of Site 1 and around 300 m upstream of its confluence with Cashmere Stream (Figure 1). The site was 100% still water habitat with grassed riparian vegetation on the true right bank and a mixture of grass, hawthorn trees, and tree stumps on the true left bank. Both banks were fenced, and stock appeared to be excluded from accessing the waterway.

Here the stream was approximately 1.4 m wide with an average water depth of 12 cm. There was no measurable water velocity on the day of sampling. The stream profile was flatter here, as compared to the incised nature of the waterway upstream at Site 1.

There was minimal canopy cover at this site, and although macrophyte and algal cover was low in October 2016, there was a substantial increase in cover (particularly of long filamentous algae) in November 2016.

The stream bed was dominated by fine substrates with approximately 16 cm depth of soft sediments covering the bed (Photo 2). It appeared that a clay base, rather than cobbles, was under these fine substrates and soft sediment. Cobbles and coarser substrates were absent, with a Substrate Index at Site 2 of 3.0.

Although the channel of Dunbar Waterway was natural earth (rather than lined), it was very straight and channelized, and appeared to be regularly maintained for drainage (e.g. macrophyte removal).

Photo 2. Site 2: Dunbar Waterway – upstream, located approximately 300 m upstream of the confluence with Cashmere Stream, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 3: Days Waterway - upstream

Site 3 was the upstream most site located on Days Waterway, approximately 250 m downstream of Halswell Road. Here the waterway was narrow (approximately 50 cm), shallow (average of 3 cm) and highly incised (Photo 3). Velocity on the day of sampling was 0.08 m / s.

A gorse hedge ran the length of the true left bank, also acting as a fence that would exclude stock access to the waterway. However, the true right bank was unfenced with pasture grass, common weeds, and bare earth.

As encountered in Dunbar Waterway, the wetted width and water depth was visibly lower, and flow was virtually absent, when the site was revisited for the fish survey in November 2016.

The stream bed was dominated by fine substrates (Substrate Index of 3.0), with an average of 13 cm of soft sediment covering the bed. Undercut banks and overhanging vegetation was largely absent and with a paucity of in-stream habitat present to support aquatic fauna.

Photo 3. Site 3: Days Waterway – upstream, located approximately 250 m downstream of Halswell Road, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 4: Days Waterway - downstream

Site 4 located on Days Waterway was approximately 700 m downstream of Site 3 and around 250 m upstream of its confluence with Henderson Waterway.

Here the waterway was narrow (average width of 70 cm) and shallow (average water depth 7 cm). Although the channel was well defined, it was covered by rank pasture grass and dock (*Rumex*) species (Photo 4). Water velocity was negligible and unable to be measured on the day of sampling.

While the true right bank was well fenced, the true left was not and stock would have been able readily access the waterway from this side. However, there was no evidence of damage to the banks by stock at this site.

On revisiting the site for the fish survey in November 2016, the channel was entirely covered by rank grass and dock.

The stream bed was dominated by fine substrates, with a Substrate Index of 3.0 and an average depth of 7 cm of silt / sand present.

Undercut banks and overhanging vegetation were largely absent at the site, and little shading due to the lack of canopy cover (Table 3; Photo 4).

Photo 4. Site 4: Days Waterway – downstream, located approximately 250 m upstream of its confluence with Henderson Waterway, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 5: Hendersons Road Branch Drain

Site 5 was located on Hendersons Road Drain Branch, approximately 70 m upstream of where it joins Henderson Waterway. Here the site had residential housing on the true right side, and semi-rural residential housing on the true left side. A lemonwood (*Pittosporum eugenioides*) hedge along the true left bank provided shading and leaf litter / organic material to the channel. The true right bank was an approximately 1.5 m strip of bare ground (with gravel, lawn clippings, leaf litter, and house-hold rubbish) between the timber-lined waterway and residential fences (Photo 5).

At Site 5, the wetted width was 1.2 m with an average water depth of 8.5 cm. Velocity on the day of sampling was 0.08 m /s.

The stream bed was dominated by fine silt / sand, however, coarser (gravel, pebble, and cobble) substrates were also present. The average Substrate Index calculated at Site 5 was 3.4.

Undercut banks and overhanging vegetation was absent from this site, as the waterway was confided to the timber-lined channel. However, gaps between the horizontal palings of the timber walls did provide some habitat for freshwater fishes, especially bullies and juvenile eels.

Photo 5. Site 5: Hendersons Road Branch Drain, located approximately 70 m upstream of the confluence of Days Waterway and Hendersons Road Branch Drain, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 6: Henderson Waterway – upstream

Site 7, located around 220 m downstream from its headwaters, was the upper most site located on Henderson Waterway. Here the stream was approximately 1.9 m wide and 10 cm deep. The waterway filled the entire timber-lined channel.

The stream bed was dominated by fine silt / sand, with a thick (26 cm) layer of soft sediments covering the bed. The average Substrate Index calculated for Site 6 was 3.0.

Undercut banks and overhanging vegetation were largely absent from this site (Table 3), as the waterway was confided to the timber-lined channel. Flaxes (*Phormium*) and gorse bushes were present on the true left and right banks, respectively (Photo 6). Gaps between the horizontal palings of the timber walls were rare, but when present these provided some habitat for freshwater fishes.

Macrophytes, dominated by the exotic curly pondweed (*Potamogeton crispus*), were abundant, with total cover approaching 50% at this site.

Photo 6. Site 6: Henderson Waterway - upstream, located approximately 70 m upstream of its confluence with Henderson Waterway, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 7: Henderson Waterway – mid

The middle Henderson Waterway site (Site 7) was located around 350 m downstream of Site 6. Here the waterway was 2.7 m wide with an average water depth of 13.5 cm. Like Site 6, the stream bed was dominated by fine silt / sand, with a Substrate Index of 3.0 and an average soft sediment depth of 80 cm.

Undercut banks and overhanging vegetation were rare at the site (Table 3). The site was largely still habitat, but some faster water, including run and riffle habitat, was present. The velocity on the day of sampling was 0.11 m / s. Macrophytes, dominated by curly pondweed, were abundant with total cover around 50% in October.

When the site was revisited in November to survey the fish community, macrophyte and filamentous algal cover was estimated as greater than 80% cover. Other than macrophytes, there was a paucity of cover or in-stream habitat for aquatic fauna.

Photo 7. Site 7: Henderson Waterway - mid, located approximately 350 m downstream of Site 6, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

Site 8: Henderson Waterway – downstream

Site 8 was the downstream most site on Henderson Waterway, located approximately 700 m downstream of Site 7 and 120 m upstream of its confluence with Cashmere Stream.

Here the waterway was on average 2.95 m wide, with water depth of around 20 cm. The site was largely run habitat with a velocity of 0.17 m / s on the day of sampling.

There was little canopy cover or stream shading at the site, despite the hawthorn hedge along the true right bank.

Henderson Waterway was highly channelized and incised, and undercut banks and overhanging vegetation were rare at the site (Table 3). With the exception of macrophytes, there was little cover suitable for aquatic fauna available at the site.

Macrophytes, dominated by curly pondweed, were very abundant in October 2016, with total cover exceeding Canterbury's Land and Water Regional Plan recommended guideline of a maximum total cover of 50% at site 8. Macrophyte cover had noticeably increased when the site was revisited for the fish survey in November 2016.

Photo 8. Site 8: Henderson Waterway - upstream, located approximately 700 m downstream of Site 7 and 120 m upstream of its confluence with Cashmere Stream, looking upstream (top left) and downstream (top right), looking into the channel (bottom).

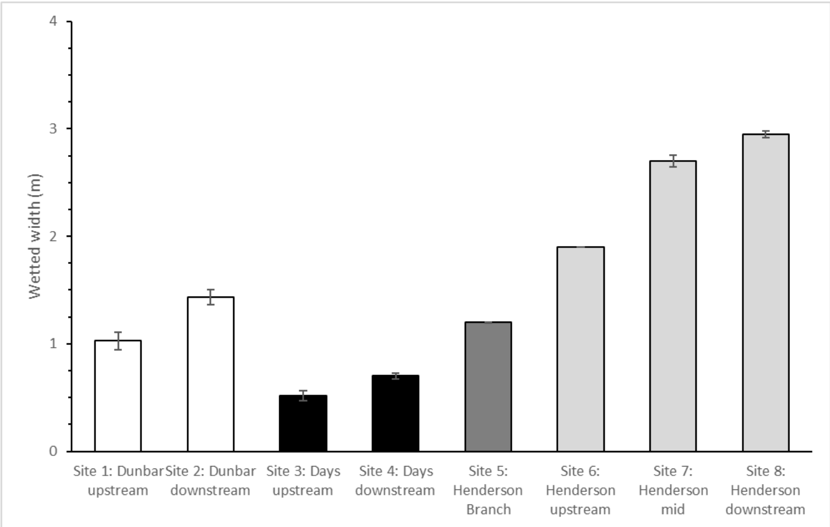
Wetted width and water depth

Wetted width was greatest in the mid and downstream most Henderson Waterway sites (Sites 7 and 8), and narrowest in the two Days Waterway sites (sites 3 and 4) (Figure 7).

Water depth showed a similar pattern with the greatest depths recorded in the two downstream Henderson Waterway sites (sites 7 and 8) and the shallowest depths recorded in the two Days Waterway sites (sites 3 and 4) (Figure 7). Site 1: Dunbar Waterway – upstream had similar water depth to Site 4: Days Waterway – upstream, while Site 2: Dunbar Waterway had similar water depth to Site 7: Henderson Waterway – mid.

Not surprisingly, both wetted width and water depth was greatest at the downstream site/s in each of the waterways surveyed (Figure 7).

It's possible that Days Waterway at Site 3 dries during the summer months when rainfall events are relatively infrequent.



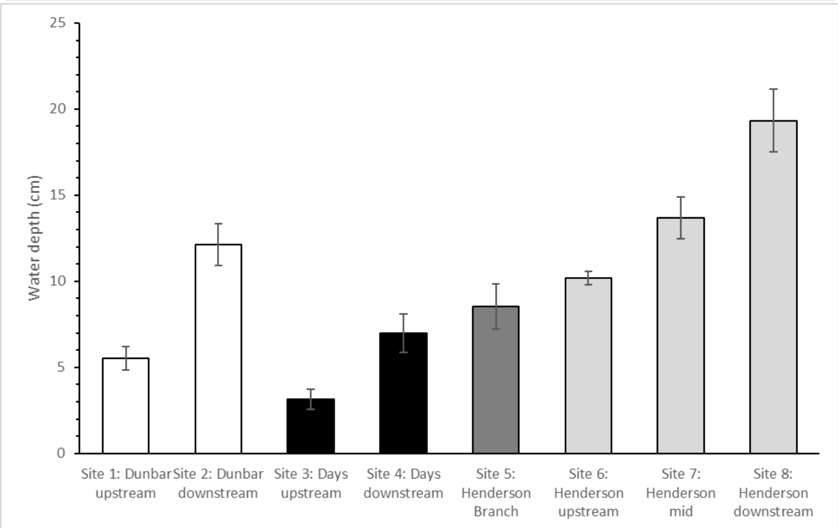


Figure 7. Mean (±1SE, n = 3) wetted width (m) (top) and water depth (cm) (bottom) measured once at each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

Substrate index

The substrate index (SI), calculated from five replicate measures of substrate composition taken along each of the three transects at each site, was 3.0 for all sites, expect Site 5: Hendersons Road Branch Drain, indicating the bed substrates were dominated by fine silt and sand (Figure 8). Slightly coarser substrates, of pebbles and cobbles, were present at Site 5: Hendersons Road Branch Drain (SI score 3.5).

Fine sediments (<2 mm diameter) were estimated to cover much (>80%) of the waterway bed at the majority of sites. This high cover of fine sediment at all sites exceeded the LWRP guideline of maximum 20% cover for Banks Peninsula waterways. This high cover of fine sediment was also reflected in the estimated embeddedness scores, as discussed below.

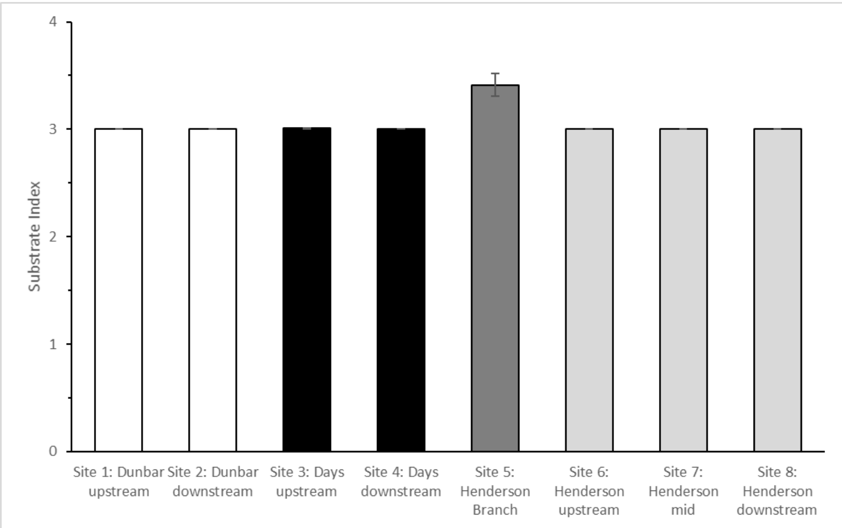


Figure 8. Mean (±1SE) substrate index calculated from substrate composition measures recorded at five locations along each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

Embeddedness

Percent embeddedness is a measure of the degree to which coarse substrates (e.g. gravel and cobbles) are surrounded and buried by fine substrates (e.g. silt and sand).

Sites with the lowest SIs had the highest embeddedness scores, which is unsurprising given that a low SI indicates bed substrates dominated by fine particles, which are also the particles that embed (surround) coarser substrates.

Percent embeddedness was high across all sites with 100% embeddedness recorded at all sites, except Site 5: Hendersons Road Branch Drain (Figure 9). Embeddedness was estimated at 87% in Site 5, where pebbles and cobbles were also present (Figure 8 and Figure 9).

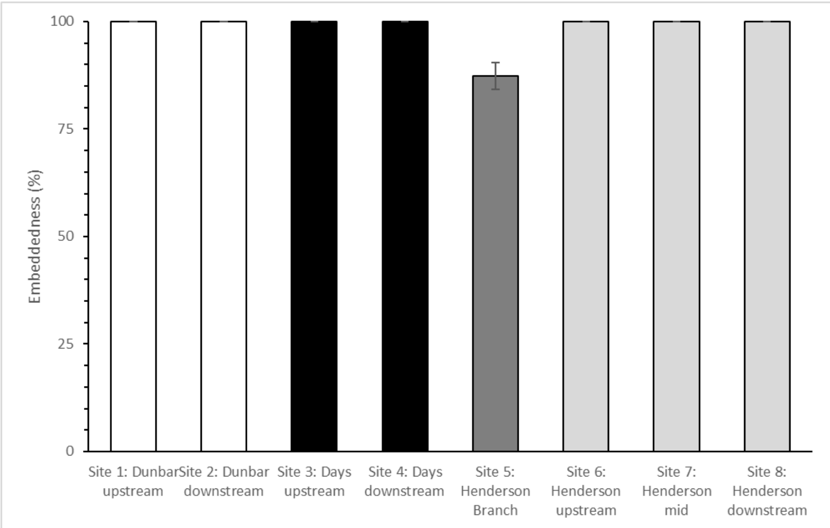


Figure 9. Mean (±1SE) percent embeddedness recorded at five locations along each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

Soft sediment depth

Soft sediment depth was greatest in Site 7: Henderson Waterway – mid, with an average depth of 80 cm of soft / fine sediment covering the stream bed (Figure 10). The other sites surveyed had soft sediment depths ranging between 7 cm (at Site 4) and 26 cm (at Site 6).

Dunbar and Days Waterways appeared to have a clay base beneath the soft sediment dominated bed, while stony substrates were apparent under the soft sediments in Henderson Road Drain Branch and Hendersons Waterways.

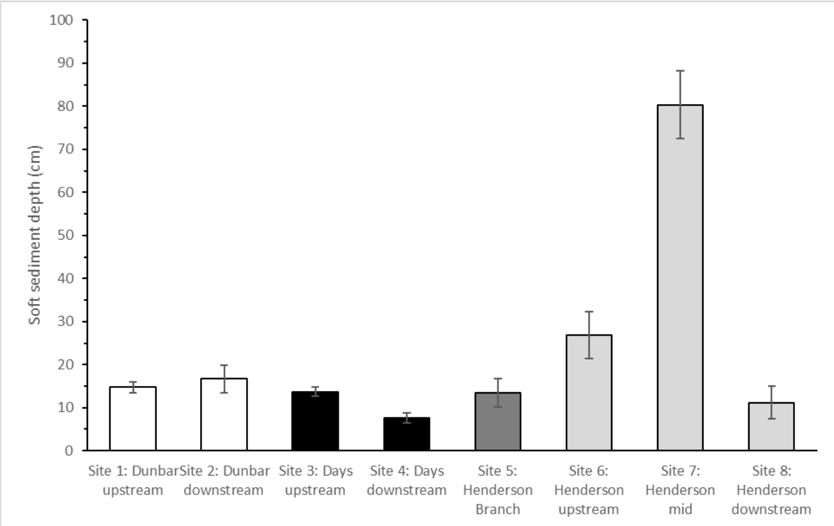


Figure 10. Mean (±1SE) soft sediment depth recorded at five locations along each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

Macrophytes

The percentage that macrophytes cover the stream bed was relatively low across all sites when the habitat was assessment and macroinvertebrates were surveyed in October 2016. However, when sites were revisited (approximately 2-3 weeks later) to survey the fish community, macrophyte cover was substantially greater and especially at sites 7 and 8 in Henderson Waterway.

Emergent macrophyte cover (in October) was relatively low at all sites surveyed. No value has been set for total or emergent macrophyte cover (as a Freshwater Outcome) for Banks Peninsula waterways, however, emergent macrophyte cover was below the maximum of 30% cover recommended for spring-fed – plains waterways in the LWRP (Figure 11).

Total cover of macrophytes was variable across sites, with sites in Henderson Waterway having the highest total cover (between 50 & 75%) recorded in October 2016. Site 8: Henderson Waterway – downstream would have exceeded the maximum of 50% cover recommended in the LWRP for spring-fed – plains waterways, but no value has been set for Banks Peninsula waterways.

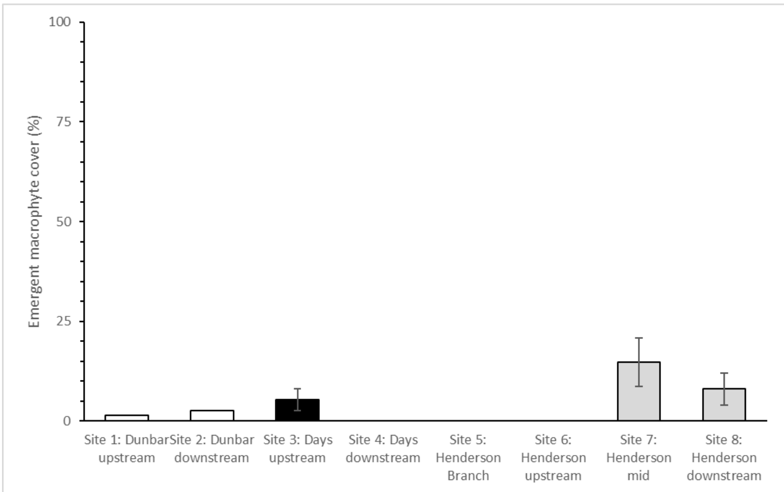
The total cover of macrophytes at all Henderson Waterway was much greater in mid-November when sites were revisited for the fish surveys.

The sparse macrophyte cover at Site 1: Dunbar Waterway – upstream consisted of the exotic species, floating sweetgrass (*Glyceria fluitans*) and the native floating macrophyte, duckweed (*Lemna disperma*). Site 2: Dunbar Waterway – downstream, with slightly greater total cover of macrophytes, was dominated by the commonly occurring exotic species, curly pondweed (*Potamogeton crispus*), as well as the native macroalga *Nitella hookeri* and the floating aquatic fern *Azolla rubra*.

Of the macrophytes present at Site 3: Days Waterway – upstream, introduced watercress (*Nasturtium officinale*) dominated the cover. The bed of Site 4: Days Waterway – downstream was dominated by pasture grasses and dock (*Rumex* species).

Nitella hookeri and duckweed dominated the macrophyte and algal cover at Site 5: Hendersons Road Branch Drain.

The three sites in Henderson Waterway had the greatest diversity of macrophytes, with a number of the commonly occurring exotic species, such as creeping buttercup (*Ranunculus repens*), watercress, water forget-me-not (*Myosotis laxa*), *Azolla rubra*, and duckweed present. Curly pondweed dominated the macrophyte community at these sites, contributing to approximately 50 – 80% of total macrophyte cover present.



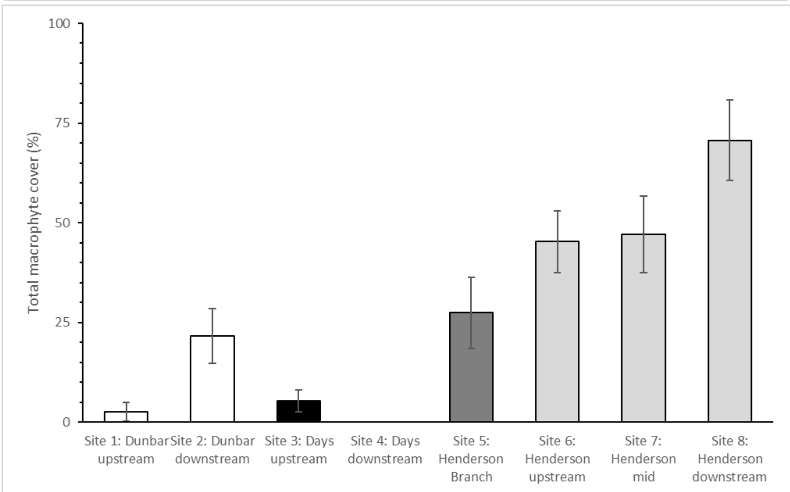


Figure 11. Mean (±1SE) macrophyte cover (top: emergent; bottom: total) recorded at five locations along each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars. No value has been set by the LWRP for Banks Peninsula waterways.

Filamentous algae

Long (>20 mm) filamentous algae was sparse in, or absent from, most sites surveyed, with the greatest total cover estimated in Site 3: Days Waterway – upstream (Figure 12). This estimate was taken in October 2016, when the aquatic habitat and macroinvertebrate community was assessed. Total filamentous algal cover in all sites surveyed in October 2106 was below the LWRP guideline of 20% (maximum) cover for Banks Peninsula waterways (Figure 12).

When the sites were revisited in November to assess the fish community, filamentous algae cover was markedly greater at some sites, and at Site 3 total cover was estimated at around 70%, which exceeded the LWRP guideline of 20% (maximum) cover for Banks Peninsula waterways.

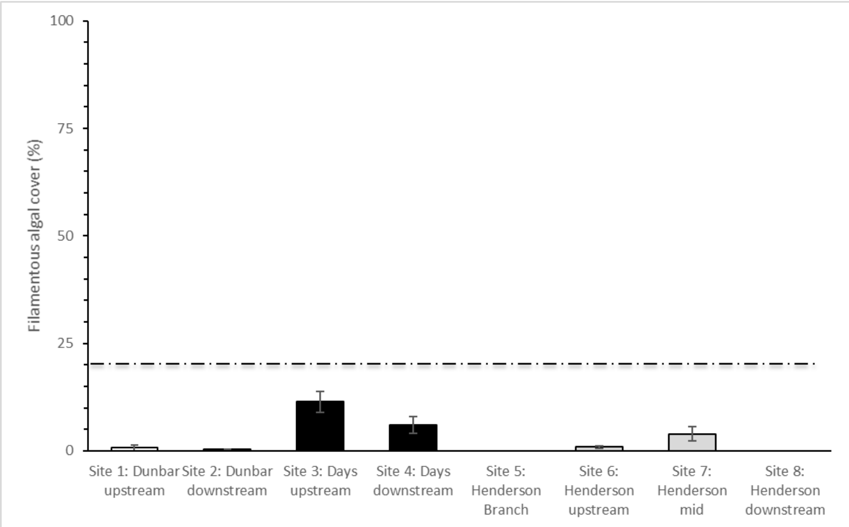


Figure 12. Mean (±1SE) filamentous algal (long, >20 mm) cover recorded at five locations along each of three transects at the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars. The dashed lines indicate the maximum cover of long (> 20 mm) filamentous algae recommended for Banks Peninsula waterways by the LWRP.

Macroinvertebrate community

Overview

A grand total of 60,068 macroinvertebrates, belonging to 44 taxonomic groups, was collected from the 8 sites surveyed in Dunbar, Days, Hendersons Road Branch, and Henderson Waterways in October 2016.

The macroinvertebrate community at all sites was dominated by taxa typical of degraded lowland waterways, with only a few representatives from the pollution-sensitive or "clean-water" EPT taxa present.

The most diverse group was the true flies (or two-winged flies, Diptera) with 18 different taxa recorded at the 8 sites. Caddisflies (Trichoptera), snails and bivalves (Mollusca), and crustaceans were the next most diverse groups, with 5, 4 and 4 different taxa, respectively, followed by aquatic beetles (Coleoptera, 2 taxa), segmented worms (Annelida, 2 taxa), and true bugs (Hemiptera, 2 taxa). Other taxa encountered included aquatic mites (Acarina), *Hydra* (Cnidaria), springtails (Collembola), nematods and nemertea, the damselfly *Xanthocnemis* (Odonata), and flatworms (Platyhelminthes).

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

Potamopyrgus antipodarium, the freshwater clam *Sphaerium*, aquatic worms (Oligochaeta), and ostracods were found at all eight sites surveyed. Flatworms (Platyhelminthes) were encountered at all sites, with the exception of Site 3: Days Waterway – upstream.

Caddisflies were also present at all sites, however, the species present at each site varied, with the algal-piercing purse-cased caddis *Oxyethira albiceps* being the only caddis found at the majority of sites surveyed (all sites except Sites 5 & 6).

Fifteen macroinvertebrate taxa were found in very low numbers and only recorded from one, or two, sites. These included freshwater leeches (Hirudinea), Hydra (Cnidaria), scirtid beetles (Coleoptera), and twelve true flies (Diptera: *Austrosimulium*, mosquitoes (Culicidae), Ephydridae, Muscidae, *Paralimnophila*, *Polypedilum*, Psychodidae, Sciomyzidae, Stratiomyidae, Tanytarsini, and *Zelandotipula*).

The cased caddisflies *Triplectides cephalotes* and *Oecetis unicolor* were each found only at one site, and in very low numbers (Sites 1 and 2, respectively). The stick-cased caddis *Hudsonema amabile* was found only at Site 5: Hendersons Road Branch Drain, but in relatively high numbers.

A small kēkēwai / freshwater crayfish (*Paranephrops zealandicus*) was captured, during the electric-fishing survey at Site 8: Henderson Waterway – downstream (30 mm orbit-carapace length – measure from behind the eye, along the top, centre of the back, to the end of the carapace). The presence of this species is of conservation interest as it is listed as "at risk, declining" (Grainger et al. 2013).

Total abundance

Similar numbers of macroinvertebrates were collected from Dunbar and Days Waterways and Hendersons Road Branch Drain, however, many more individuals were collected from the three Henderson Waterway sites (Figure 13).

Total abundance ranged from 1,881 individuals in Site 1: Dunbar Waterway – upstream, to 15,321 individuals in Site 8: Henderson Waterway – downstream. Henderson Waterway (Sites 6, 7, and 8) had a much greater number of the relatively pollution tolerant mud snail *Potamopyrgus antipodarium* and, to a lesser extent, the freshwater amphipod *Paracalliope fluviatilis*, compared to the other sites surveyed.

Henderson Waterway was the largest waterway (i.e. the greatest water depths and wetted widths, and more available habitat) surveyed, so not surprisingly these three sites also had the greatest total abundances[8]. While Dunbar and Days Waterways, and particularly the upper sites surveyed along these two waterways, were much smaller (in both water depth and wetted width) than Henderson Waterway. The smaller size, and the potential for these sites to dry or have only limited water availability in the summer months, may influence total abundance of macroinvertebrates at Sites 1, 2, 3, 4, and 5 (Figure 13).

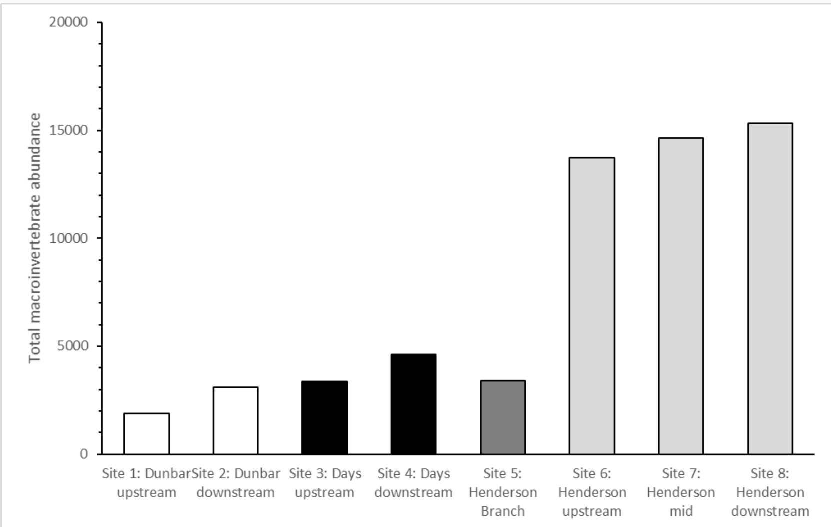


Figure 13. Total abundance of macroinvertebrates collected in a single kick-net sample from each of the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

[8] Larger systems tend to have more habitat and therefore support more species and individuals.

Taxonomic richness

Taxonomic richness was variable among sites, ranging from 11 to 26 macroinvertebrate taxa (Figure 14). Site 4: Days Waterway – upstream had the most diverse macroinvertebrate community, with 26 taxa encountered. Site 3: Days Waterway – downstream and Site 6: Henderson Waterway – upstream had the least diverse (lowest macroinvertebrate richness) with 11 taxa collected from each site.

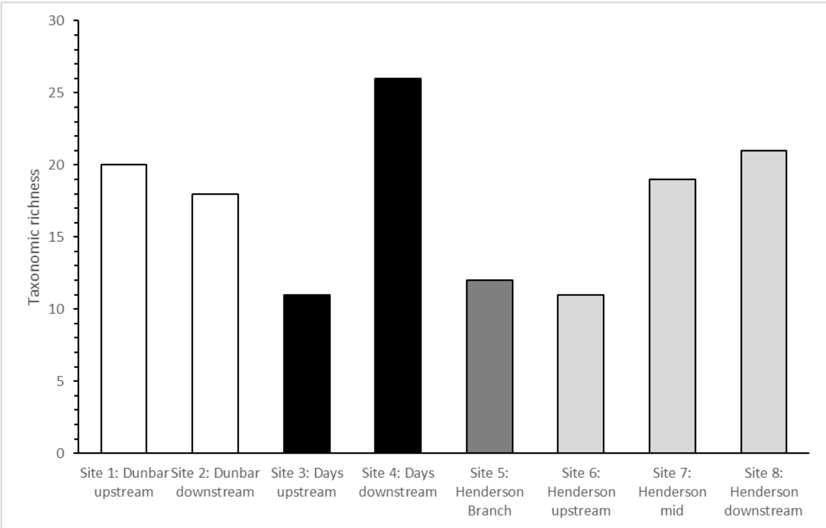


Figure 14. Taxonomic richness of macroinvertebrates collected in a single kick-net sample from each of the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

EPT taxa

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.

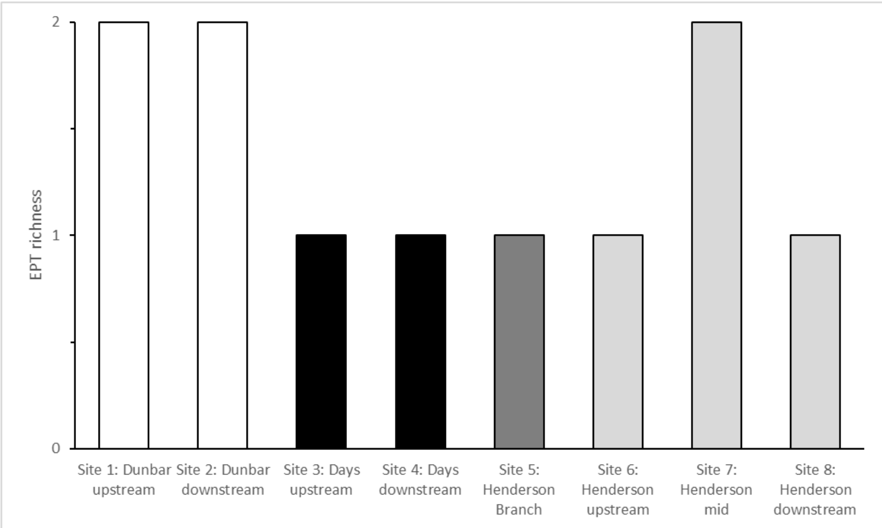
EPT richness was relatively similar, and low, across all eight sites, with only 1 or 2 EPT taxa found at each site (Figure 15). Moreover, caddisflies were the only group of "clean-water" EPT taxa encountered; mayflies and stoneflies were absent from all sites.

Of the five caddis taxa collected across all sites, the more pollution-sensitive taxa such as the stick caddis *Hudsonema amabile* and *Triplectides cephalotes*, and the stony-cased caddis *Oecetis unicolor* were found only at one site (Site 2: Dunbar Waterway), and usually in very low numbers. On the other hand, the pollution-tolerant algal-piercing caddisfly species, *Oxyethira albiceps* and *Paroxyethira hendersoni*[9], were found at the majority of sites surveyed (Figure 15). *Oxyethira albiceps* was found at all except two sites (i.e. 75% of sites surveyed).

Caddisflies (Trichoptera) made up a very small (<5%) proportion of the community at all sites. Site 5: Hendersons Road Branch Drain, with its slightly coarser substrate present, had the

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

greatest relative abundance of caddisflies, but still only 4.97% of the macroinvertebrate community present (Figure 16).



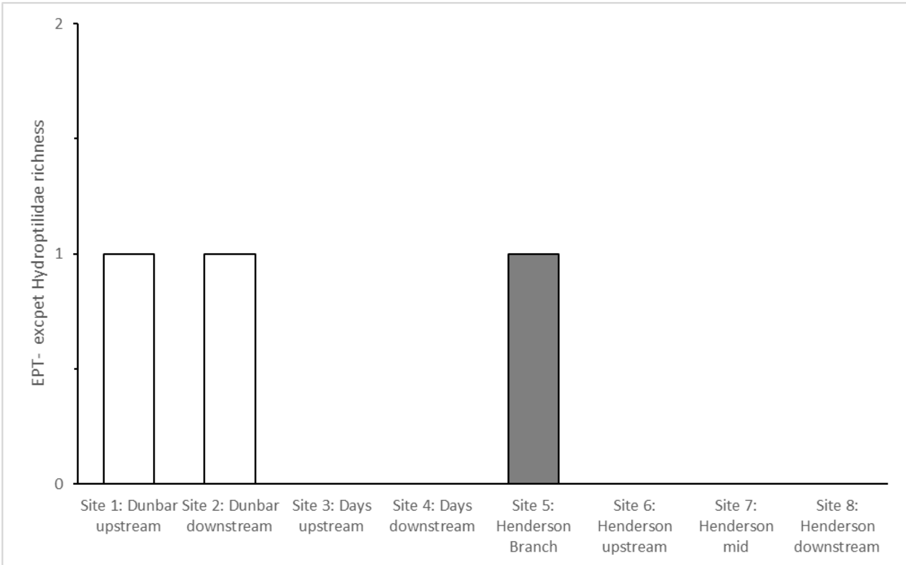


Figure 15. Total number of EPT taxa (top) and EPT taxa excluding pollution-tolerant Hydroptilidae caddis (bottom) collected in a single kick-net sample from each of the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

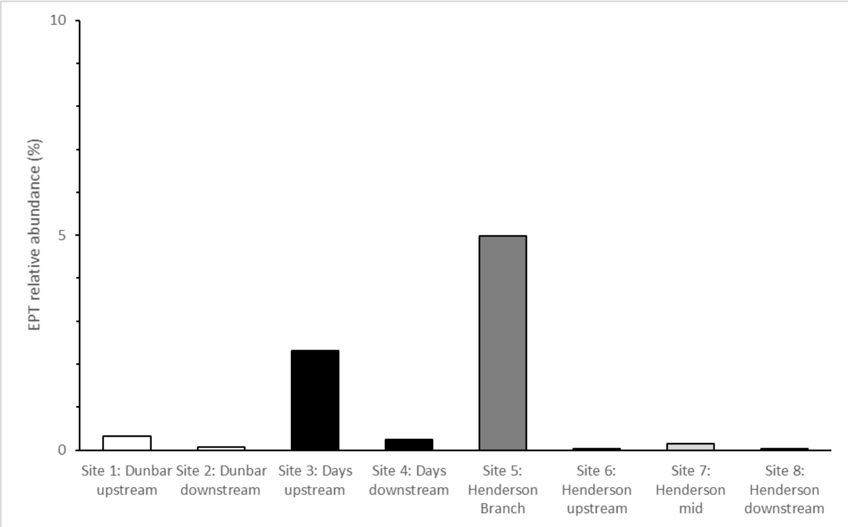


Figure 16. Relative abundance of EPT taxa collected in a single kick-net sample from each of the eight sites surveyed within the two Dunbar Waterway sites (white bars), Days Waterway sites (black bars), Henderson Road Drain Branch Waterway (dark grey bar), and the three sites along Henderson Waterway (light grey bars).

Macroinvertebrate Community Index

Although there was slight variability in MCI-sb[10] scores, all sites had "poor" stream health with "probable severe enrichment" (based on the water quality categories of Stark and Maxted 2007) (Figure 16). MCI scores for Site 2: Dunbar Waterway – downstream and Site 5: Hendersons Road Branch Drain were approaching the "fair" stream health category.

QMCI is considered a better indicator of "health"[11], as in addition to presence of macroinvertebrate taxa it also into account their abundances. QMCIs scores were between 2.5 and 2.7 for all sites, except for Site 5: Hendersons Road Branch Drain (Figure 16).

QMCI scores below 4 indicate "poor" stream health with "probable severe enrichment" (based on the water quality categories of Stark and Maxted 2007). Hendersons Road Branch Drain had a QMCI of 4.8, indicating "fair" stream health with "probable mild enrichment".

More importantly, none of the sites surveyed were above the LWRP guideline of a minimum QMCI of 5[12] (Figure 16).

[10] Soft-bottomed MCI scores were used for all sites in this study.

[11] This may not be the case if samples are collected many days apart and when environmental conditions (e.g. water permanence, algal growth) may influence community composition. MCI is likely to be less sensitive, than QMCI, to change in macroinvertebrate community composition through time (see Stark and Maxted 2007 for discussion).

[12] This guideline of a minimum QMCI score of 5 is for both Banks Peninsula waterways (as compared to in this report) and spring-fed – plains waterways.

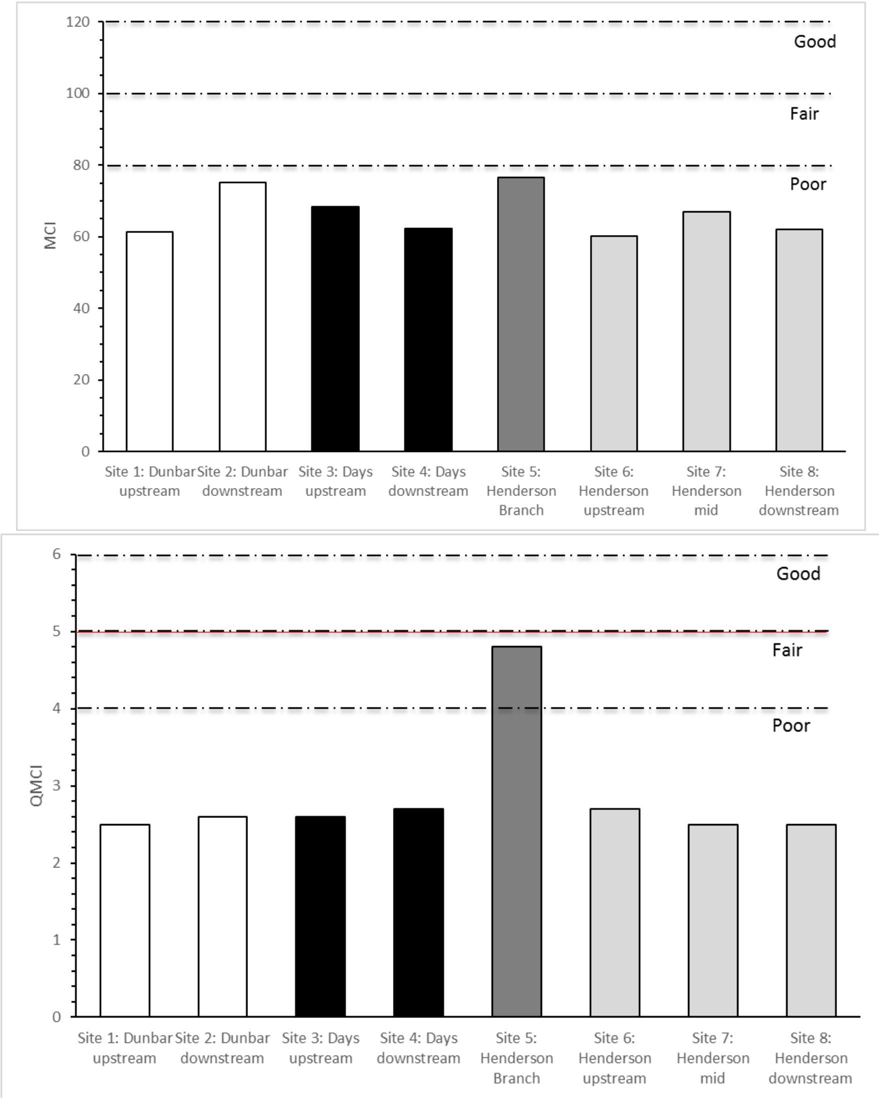


Figure 17. Macroinvertebrate Community Index (MCI) scores (top) and QMCI scores (bottom) for the eight sites surveyed within the three waterways. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars. The dashed black lines indicate the water quality categories of Stark and Maxted (2007), where “poor” = “probable severe enrichment”, “fair” = “probable moderate enrichment”, and “good” = “doubtful quality or possible mild enrichment”. The “excellent” category has not been shown. The red line on the QMCI graph indicates the guideline of minimum QMCI 5 for Banks Peninsula waterways.

Community composition

Community composition was generally similar between sites within each waterway, with relative abundances being consistent between Sites 1 and 2, and Sites 6, 7 and 8. However, Sites 3 and 4 (the two Days Waterway sites) differed in that snails and bivalves, and 'other'[13] dominated the macroinvertebrate community at Site 3, while crustaceans and true flies dominated the community at Site 4 (Figure 17).

There was some variability in macroinvertebrate community composition among the eight sites, with differences largely due to variance in relative dominance (percent abundance) of snails and bivalves (Mollusca), crustaceans, true flies (Diptera), and 'other'.

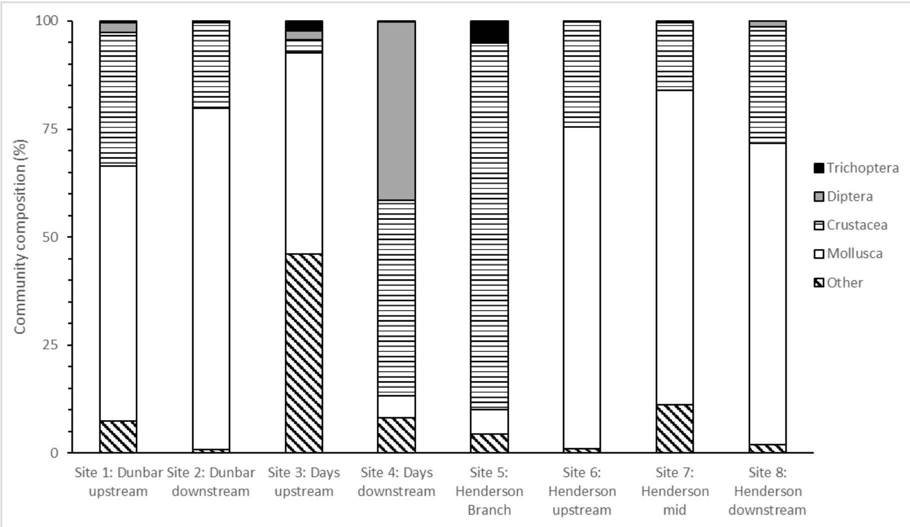


Figure 18. Macroinvertebrate community composition (%) found at the eight sites surveyed in October 2016. "Other" includes *Hydra* (Cnidaria), aquatic mites (Acarina), springtails (Collembolla), leeches (Hirudinea), true bugs (Hemiptera), aquatic beetles, (Coleoptera), nematods (Nematoda), flatworms (Platyhelminthes) and damselflies (*Xanthocnemis zelandica*, Odonata).

The NMDS ordination and ANOSIM results also indicated subtle differences in macroinvertebrate community composition among the waterways (ANOSIM R = 0.652; P = 0.013) (Figure 18). This was largely due to minor differences between Dunbar and Henderson Waterways and Days and Henderson Waterways.

Differences between Dunbar and Henderson Waterways were a result of differences in abundances of the mud snail *Potamopyrgus antipodarum*, the amphipod *Paracalliope fluviatilis*, and ostracods (Appendix 2).

Differences between Days and Henderson Waterways were a result of differences in abundances in Potamopyrgus antipodarum, ostracods, orthoclad midge larvae, and nematods, as well as the absence of *Paracalliope fluviatilis* in the Days Waterway sample, and absence of ostracods in the Henderson Waterway sample (Appendix 2).

[13] "Other" includes, *Hydra* (Cnidaria), aquatic mites (Acarina), springtails (Collembolla), leeches (Hirudinea), true bugs (Hemiptera), aquatic beetles, (Coleoptera), nematods (Nematoda), flatworms (Platyhelminthes) and damselflies (*Xanthocnemis zelandica*, Odonata).

However, ANOSIM indicated these subtle differences were not statistically significantly different (Dunbar and Henderson Waterways: $R = 0.917$; $P = 0.100$; and Days and Henderson Waterways: $R = 0.750$; $P = 0.100$).

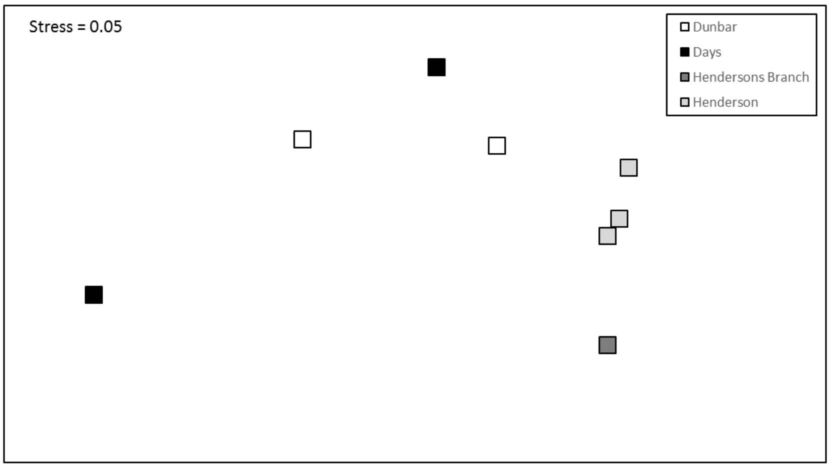


Figure 19. Non-metric multidimensional scaling (NMDS) ordination based on a Bray-Curtis matrix of dissimilarities calculated from macroinvertebrate abundance data collected from the eight sites surveyed in October 2016. White squares = Dunbar Waterway (2 sites); black squares = Days Waterway (2 sites); dark grey squares = Hendersons Road Branch Drain (1 site); and light grey squares = Hendersons Drain (3 sites). The NMDS ordination gave a good representation of the actual community dissimilarities among waterways (two-dimensional stress = 0.05). 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 163 fish, belonging to five indigenous species, were captured in the eight sites surveyed within Dunbar, Days, Hendersons Road Branch, and Henderson Waterways in November 2016. The five species[14] encountered, in descending order of total abundance (i.e. across all sites), were:

Common bully (*Gobiomorphus cotidianus*), shortfin eel (*Anguilla australis*), longfin eel (*Anguilla dieffenbachii*), upland bully (*G. breviceps*), inanga (*Galaxias maculatus*), *Gobiomorphus* species (unidentifiable bully species), *Anguilla* species (unidentifiable eel species).

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

[14] Fish were recorded as bully species (*Gobiomorphus* sp.) and eel species (*Anguilla* sp.) when they were unable to be caught and / or identified to species level. The five fish species captured across all sites assumes fish noted as bully species and eel species were one of the five identifiable species, rather than an additional species.

Species richness

The fish communities were depauperate, with species richness ranging from zero (i.e. no fish) at Sites 3 and 4 (the two Days Waterway sites) to five species encountered at Site 8: Henderson Waterway – downstream[15] (Figure 19).

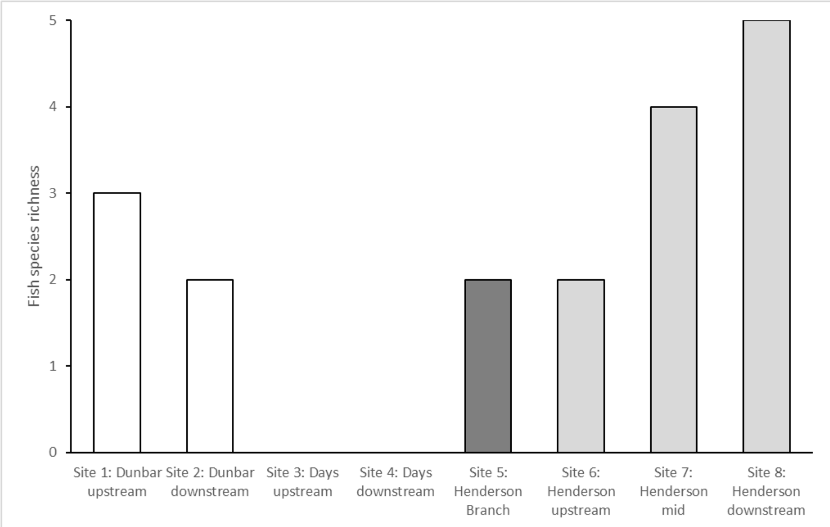


Figure 20. Number of fish species encountered, using electric fishing and / or trapping and netting techniques, at each of the eight sites surveyed in November 2016. The two Dunbar Waterway sites are shown in white bars, Days Waterway sites are shown in black bars, the Henderson Road Drain Branch Waterway site is shown in dark grey bar, and the three sites along Henderson Waterway are shown in light grey bars.

Size distribution of fish

Table 4 summarises the size and species richness information of fish captured (or seen but not captured) at the eight sites surveyed in October 2016. The largest fish captured at any site was a 1,050 mm longfin eel at Site 8: Henderson Waterway – downstream.

Shortfin eel was the most commonly encountered species, being found at all sites where fish were present (i.e. excluding Sites 3 and 4, where no fish were found). Common bullies were encountered at five sites; this species was not found at Site 2: Dunbar Waterway – downstream.

Upland bullies were only found at Sites 1, 7 and 8; inanga were caught at Sites 2, 7 and 8; while a large number (32) longfin eels were only encountered at Site 8, and this species was only caught in the baited fyke nets (Table 4).

It's worth noting that the presence / abundance of inanga can be underestimated by electric fishing techniques (Joy et al. 2013), so this species may have been more abundant at Sites 2, 7 and 8; and possibly present at sites where it was not encountered in this study.

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[15] Site 8: Henderson Waterway – downstream results are the total number of species encountered using both electric fishing and trapping and netting.

Table 4. Total number of fish caught (or seen) at each of the eight sites surveyed in November 2016. Size (mm) ranges are shown in parentheses. Where the minimum and maximum size were the same, only one value is shown. *indicates fish that were not caught and size was unable to be measured or estimated. Different fishing methods were used in two of the Henderson Waterway sites: Sites 7 and 8. Halswell River sites. EF = electric fishing.

	Fishing method	Common bully	Upland bully	Bully sp.	Longfin eel	Shortfin eel	Eel sp.	Inanga
Site 1: Dunbar Waterway – upstream	EF	6 (35-55)	7 (40-65)			2 (500-700)		
Site 2: Dunbar Waterway – downstream	EF					1 (500)		1 (100)
Site 3: Days Waterway – upstream	EF	No fish seen or caught						
Site 4: Days Waterway – downstream	Not surveyed; not enough water							
Site 5: Hendersons Road Branch Drain	EF	2 (35-40)		5*		13 (120-500)	3*	
Site 6: Henderson Waterway – upstream	EF	7 (25-60)				9 (180-400)		
Site 7: Henderson Waterway – mid	Fyke nets	2 (35)	3 (35-60)			8 (200-500)		1 (65)
	Gee minnow traps	10 (30-50)	2 (40-45)			1 (300)		
Site 8: Henderson Waterway – downstream	EF	15 (30-80)	9 (40-65)			11 (80-280)		4 (90-100)
	Fyke nets	1 (35)			32 (500-1050)			1 (85)
	Gee minnow traps	6 (35-50)						1 (50)

Community composition

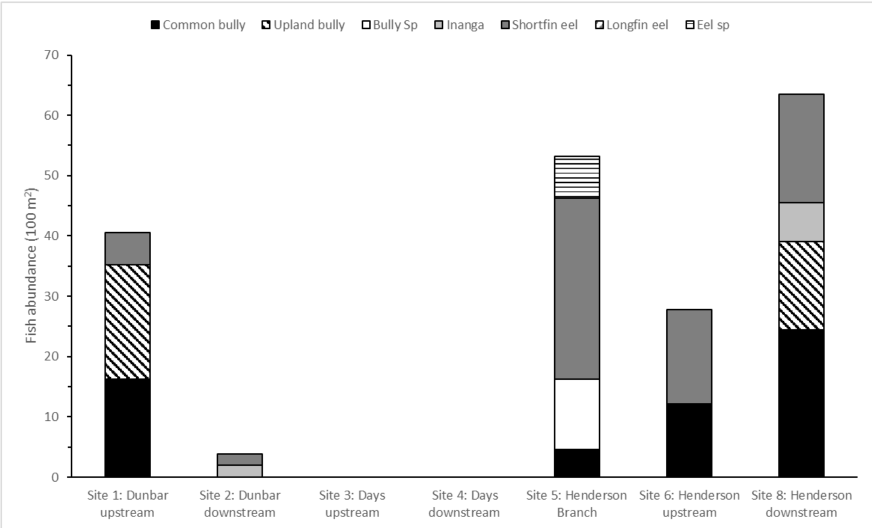
While the shortfin eel was the most commonly encountered species, it was not always the dominant species (i.e. relative abundance) at each site (Figure 20). This was especially the case at Site 1: Dunbar Waterway – upstream, where common and upland bullies were more abundant than shortfin eels. Conversely, shortfin eels made up a large number of the individuals captured at Sites 5, 6, 7, and 8 (the Hendersons Road Branch and Henderson Waterway sites).

The unidentified bullies and eels encountered at Site 5: Hendersons Road Branch Drain were likely to be common bullies and shortfin eels, as no other species of bully or eel was encountered during the electric fishing. However, as these individuals were seen but not caught, they could not be identified to species level.

Inanga only ever contributed to a small portion of fish caught[16], where this species was encountered at Sites 2, 7, and 8 (Figure 20). A single individual was captured during the

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

electric-fishing survey at Site 2: Dunbar Waterway – downstream, however, Joy et al. 2013 note that the presence / abundance of inanga can be underestimated by electric fishing techniques.



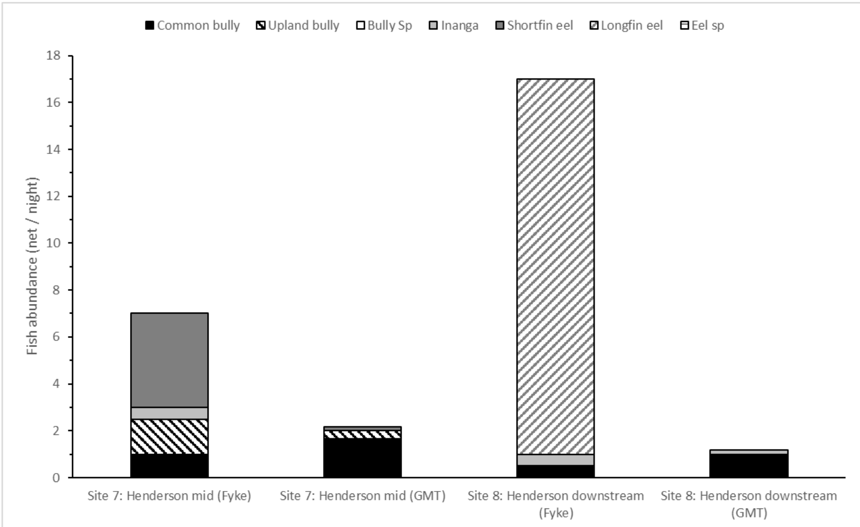


Figure 21. Total abundance of fish, separated by species, captured at each of the eight sites surveyed in November 2016. Numbers are show as catch per unit effort (CPUE): per 100 m^2 of waterway surveyed using electric fishing (top); or per net / night where baited traps and nets were set overnight (bottom).

Discussion

Ecosystem health

This ecological assessment indicated that the eight sites surveyed were generally of poor ecological health. Of the sites surveyed, only one (Site 5: Hendersons Road Branch Drain) fell within the “fair” water quality category. The remainder of sites surveyed were classified as “poor”, with probable severe enrichment.

Moreover, none of the sites were above the LWRP objective of a minimum QMCI 5.0 for Banks Peninsula waterways. These findings are similar to that of the recent survey of rural sites within the Halswell River / Huritini (Blakely 2016) and within the more urbanised Heathcote River / Ōpāwaho catchment (Blakely 2015), where 100% and 84%, respectively, of sites surveyed fell within the “poor” water quality category.

Water quality

The basic water quality parameters of conductivity, pH, dissolved oxygen, and water temperature, measured in November 2106, were within ranges expected in waterways of this type during base-flow conditions. Conductivity levels recorded were generally similar to those recorded in the Avon River, Heathcote River and Halswell River in 2013, 2015 and 2016, respectively (Blakely 2014; 2015; 2016). pH was generally circum-neutral, except for Sites 3 and 6, both of which were above the water quality standard for receiving waters of the LWRP. Dissolved oxygen concentrations were low in Site 1: Dunbar Waterway – upstream and Site 4: Days Waterway – downstream. At the time of sampling, these sites both had low water levels. Site 1 also had the highest water temperature recorded, which was approaching the maximum of 20°C recommended in the LWRP for Canterbury Rivers.

Conversely, DO concentrations, measured in November 2016, were very high in Site 2: Dunbar Waterway – downstream; Site 3: Days Waterway – downstream; and all three sites located along Henderson Waterway (Sites 6-8). These high DO concentrations were likely to have been influenced by high macrophyte and algal cover at the time of sampling, suggesting that fauna inhabiting these sites are subject to highly variable daily DO concentrations, and particularly during the spring and summer when macrophyte and algal cover may be highest.

Water temperature is also anticipated to be variable and, at times, could be markedly higher than 20°C in summer, especially in areas with little to no canopy cover or stream shading. Temperatures greater than 20°C can be stressful for aquatic fauna, and many macroinvertebrate and fish species may be excluded from waterways as a result.

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

Riparian and in-stream habitat

Riparian and in-stream conditions were degraded and found to be generally similar across all sites. Substrate indexes were low at all sites, indicating stream-bed substrates were dominated by finer particles and generally lacking in boulders and large cobbles. Coarser substrates, such as gravels and pebbles were found only at Site 5: Hendersons Road Branch Drain. Large substrata such as large cobbles and boulders were absent from all sites. These types of substrates are important egg-laying surfaces for fish and macroinvertebrates.

Henderson Waterway was likely to have coarser substrates (e.g. cobbles) under the layer of soft deposited sediment, while Days and Dunbar Waterways (and particularly the downstream reaches) were thought more likely to be clay bottomed. However, this was not able to be confirmed in this study. Hendersons Road Branch Drain had coarse substrates (gravels, cobbles), albeit embedded by fine substrates, at the bed surface. These observations need to be confirmed as they may have important implications for rehabilitation opportunities and objectives within these waterways.

Fine sediment (<2 mm diameter) covered the majority (and up to 100%) of the stream bed at all sites. There was also a thick layer of soft sediment present at many of the sites. All of these factors meant that when coarser substrata were present (e.g. cobbles; which was rare) these were highly embedded and generally unavailable to aquatic biota (for grazing, egg laying, using as refugia).

Organic matter present in the waterways was generally limited to sparse coverage of leaf litter. Log jams and other larger woody debris, which provide important habitat for in-stream fauna, were absent from all sites. Overhanging vegetation and undercut banks, which provide shading and habitat for in-stream fauna (e.g. fish), were also rarely encountered.

Canopy cover, and therefore stream shading, was also rare, with only Site 1: Dunbar Waterway – upstream having substantial stream shading as a result of a poplar shelterbelt on the true left bank. There was minimal indigenous vegetation present in the riparian zone, with the majority of sites (and along the length of these waterways) being dominated by rank grass, gorse, hawthorn, with occasional willow trees and poplar shelterbelts.

It was not surprising, therefore, that macrophyte and filamentous algal cover, which was generally low across all sites when first surveyed in October 2016, was very high when sites were revisited for the fish survey in November 2016 (see Appendix 1 for site photos from November 2016). Curly pondweed and the floating macrophytes *Lemna* (duckweed) and *Azolla* were the most commonly encountered; typical of slow-flowing waterways of this type.

Macroinvertebrate community

The macroinvertebrate community at all sites was dominated by taxa typical of low gradient, lowland waterways that have been degraded by agricultural and / or urban development. The macroinvertebrate communities were dominated by pollution-tolerant taxa, such as chironomid midges, the ubiquitous New Zealand mud snail, oligochaete worms, amphipods, and other crustaceans, reflecting the paucity of habitat suitable for more ‘sensitive’ and diverse macroinvertebrate communities. Although there were some subtle differences in macroinvertebrate community composition, the community found was generally similar at each site. Moreover, few pollution-sensitive or “clean-water” EPT taxa were found, and generally represented by more tolerant caddisflies (a total of five caddisfly taxa, with a maximum of two found at any one site). The most “pollution-tolerant” EPT taxa – the hydroptilid caddisflies, *Oxyethira albiceps* and *Paroxyethira hendersoni* – were found at all sites except Site 5:

Hendersons Road Branch Drain. It is plausible that one, or both, of these species occur at Site 5, but were not detected by the kick-net sampling.

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

Nevertheless, it is important to note that a single kēkēwai (freshwater crayfish, *Paranephrops zealandicus*), an “at risk, declining” species, was captured during the electric-fishing survey in Site 8: Henderson Waterway – downstream. Kēkēwai can be difficult to survey, especially in waterways with high macrophyte cover, so it is likely that the downstream reaches, and possibly other parts of the waterways surveyed in this study, support kēkēwai. For example, Belinda Margetts (CCC Waterways Ecologist) advised Boffa Miskell that stream maintenance contractors had noted the presence of kēkēwai in Dunbar Waterway, near the confluence with Cashmere Stream (downstream of Site 2).

Whilst conducting the CREAS surveys, kākahi (freshwater mussels; both alive and feeding individuals and empty shells) were observed in downstream reaches of Henderson Waterway. Like kēkēwai, kākahi is a species of conservation interest, listed as “at risk, declining” (Grainger et al. 2013).

Moreover, both kēkēwai and kākahi are today known from only a few of Christchurch’s waterways, and tend to be most abundant in less urbanised areas, including Cashmere Stream (McMurtrie and James 2013) and, to a lesser extent, the Heathcote River / Ōpāwaho and Cashmere Stream. Dunbar, Days, Hendersons Road Branch, and Henderson Waterway all flow into Heathcote River / Ōpāwaho and Cashmere Stream. For example, a single kēkēwai was found in the upper reaches of the Heathcote River / Ōpāwaho during surveying in 2012 and again in 2014 (Taylor and Blair 2012; Blakely 2015).

Fish community

It is important to remember that although the sites surveyed in this study were classified as having “poor” or “fair” water quality (based on the macroinvertebrate community present [QMCI]), native fish species were present at the majority of these sites, albeit with generally low diversity and abundances likely reflective of the paucity of in-stream habitat.

Shortfin eels, which were found at six (of the eight) sites, and the ubiquitous common bully, encountered at five sites, can be considered relatively ‘pollution-tolerant’ freshwater fish species. Both of these species are listed as “not threatened” and can be found in highly degraded conditions, including stormwater fed waterways and wetlands with very high soft sediment loads.

Of greater interest, inanga and longfin eels were found inhabiting parts of Dunbar Waterway (inanga) and Henderson Waterway (inanga and longfin eels). Both longfin eel and inanga are of conservation interest, and are currently listed as “at risk, declining” (Goodman et al. 2013).

A surprising number of longfin eels, including some very large individuals, were captured in the baited fyke nets set overnight at Site 8. As Site 8 was located only 120 m upstream of Henderson Waterway’s confluence with Cashmere Stream, it’s plausible that these fish were attracted to the bait in these fyke nets travelling up from Cashmere Stream, or lower reaches of Henderson Waterway, where the habitat conditions are likely to be more suitable for these large fish to reside (e.g. undercut banks, deep pools).

Both species of eel, common bully, and inanga are all migratory species, moving between freshwater and the sea to complete their life cycles. While we recorded a range of sizes for shortfin eels among all of the sites, suggesting good recruitment and access to and from the sea, only large longfin eels were encountered. However, as discussed above, the longfin eels were likely residents of Cashmere Stream, or the lower reaches of Henderson Waterway, rather than locally at Site 8 – due to the paucity of habitat suitable for fish of this size.

Recommendations for waterway realignment & enhancement

Often there are multiple and interrelated stressors at play affecting ecosystem health in freshwater habitats. It's not always straightforward to determine the main drivers responsible for loss of 'sensitive, clean water' taxa. However, lack of good quality and diverse riparian and in-stream habitats is likely one of the main parameters determining the macroinvertebrate and fish communities present in Dunbar, Days, Hendersons Road Branch, and Henderson Waterways.

We recommend the following actions be incorporated in the naturalisation projects for these waterways.

- Best practice stormwater management techniques, particularly in areas of future residential development or where presented with opportunities to pass realigned waterways through constructed treatment facilities (e.g. stormwater wetland basins). Untreated stormwater brings with it fine sediments and contaminants, which can then smoother the stream bed or be directly consumed by freshwater fauna. Reducing inputs of fine sediments is essential when enhancing habitat for aquatic species, such as kākahi, pollution-sensitive macroinvertebrate taxa, and many freshwater fishes. Poor water quality due to untreated stormwater inputs can pose as a chemical barrier to many fish species. Kākahi inhabit areas of soft sediments in between coarser substrates, but can be smothered by excessive fines entering and settling on the stream bed.
- Removal of timber-lined channels, and reinstatement of natural, gently-graded banks. Timber-lined channels constrain waterways, reducing flow variability, and provide little opportunity for habitat for fish and other aquatic fauna to seek refuge from the main channel.
- Realign channels to increase sinuosity, and create natural, gently graded banks. These waterways are currently highly incised and channelized, which results in homogeneous in-stream habitat conditions.
- Meandering sections will bring a greater diversity in flow conditions (e.g. pools, riffles, runs), providing habitat for a wider range of aquatic fauna. Many species of fish and macroinvertebrates have specific flow and habitat requirements.
- The inclusion of pools, where water levels allow, with overhanging vegetation will create habitat (which is currently lacking) for large longfin /shortfin eels, inanga, giant bullies, kēkēwai, and other species.
- Riffle habitat, where gradient allows, will provide faster flowing sections suitable for a variety of fish (e.g. juvenile eels and possibility also fast-water species such as bluegill bullies) and macroinvertebrate species (e.g. caddisflies).
- Inclusion of a diversity of in-bank and in-stream habitat for fauna. The addition of root balls, tree stumps, or other structures (open-ended pipes) to create stable undercut

banks and other habitat would provide a greater variety of habitat for fish (including large longfin eels, other fishes) and kēkēwai.

- Changes to the current maintenance regimes of macrophyte cover in Christchurch's waterways is essential for improving ecological health. Where little other diversity of habitat or cover is available, macrophyte beds (including those dominated by exotic species) provide refugia for fishes, kēkēwai and other macroinvertebrates. Regular removal of macrophytes, to maintain flood conveyance, almost certainly detrimentally impacts the ecology of waterways and in-stream fauna. When macrophytes are mechanically removed, sediments are re-suspended, which affects water quality, in-stream habitat is lost, and fish and macroinvertebrate mortality increases due to both the physical removal of macrophytes and changes to water quality (increased turbidity, decreased dissolved oxygen).
- Water levels and water permanence need to be considered when designing for the realignment of the waterways. For example, water depths in Days Waterway (and particularly upstream reaches) were low, may be variable seasonally with some reaches possibly drying in the summer months. Waterways such as this may need to be designed to specifically:
    - include a low flow channel, or similar, to ensure adequate aquatic habitat persists throughout the year for in-stream fauna; or
    - develop as a wetland area, if spaces allows.
- Improving habitat conditions for kēkēwai and kākahi, especially in Henderson and Dunbar Waterways where they already occur in downstream reaches. This would include well-shaded areas, making best use of indigenous vegetation, and
    - areas of soft substrates along stable banks, interspersed by pebble-cobble habitat (e.g. for kākahi); and
    - creating stable undercut banks and areas with and that retain coarse woody debris and log jams (e.g. for kēkēwai).
- Large cobbles and emergent and submerged boulders were also limited or entirely absent from these waterways. A variety of bed substrates, including large cobbles and boulders are important for egg-laying surfaces for both fish and aquatic insects. Many freshwater fishes and insects have highly specific egg-laying requirements; some species deposit eggs masses on the undersides of boulders in stream channels, while some aquatic insects specifically select emergent boulders, with specific downstream water velocities for oviposition sites. The successful recruitment of aquatic insect species, which in turn provide food sources for many of New Zealand's native freshwater fishes, is partly dependent on the availability of suitable oviposition habitat.
- Retrofitting of actual and potential barriers, including those already identified along the waterways, so as to enhance and maintain fish passage.
- Adapting maintenance practices to allow macrophyte beds, debris clusters, log jams, to accumulate. These would provide habitat, which is currently lacking, but important for a variety of species, including kēkēwai.
- Planting of riparian margins with ecologically sensitive, indigenous species. Include locally-sourced native species, and preferably indigenous and evergreen, so as to provide organic resources for in-stream fauna (e.g. kēkēwai, filter feeding

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

- Use ecologically suitable plant species within the riparian margins, including planting vegetation up to, and overhanging, the water's edge. Use plants with flexible and low-density foliage where it's important to maintain flood capacity.
- Improve riparian planting to provide canopy cover for increased shading of the stream. This will not only reduce excessive macrophyte growth, but also provide organic (leaf litter) resources for the macroinvertebrate community, help regulate water temperature and dissolved oxygen levels, and assist in the establishment of stable undercut banks for aquatic faunal habitat.
- Consider options to remove some of the excessive soft / fine sediment cover in some waterways (e.g. localised removal using tools such as the Sand Wand; or larger-scale removal with heavy machinery and including a faunal salvage programme). This needs to be done in conjunction with management of stormwater and runoff, so as to avoid new sediments entering the waterways.
- Development of a salvage programme to rescue and relocate fish, kēkēwai and kākahi from the waterways prior to in-stream and realignment works (but also see bullet point below).
- Employ alternate rehabilitation options, using 'softer' approaches in order to retain existing populations of less mobile target taxa (e.g. kēkēwai and kākahi). For example, downstream reaches of Dunbar Waterway (near the confluence with Cashmere Stream) are reported to support a population of kēkēwai (this species has been encountered by CCC contractors during waterway maintenance). Kākahi were also found inhabiting the lower reaches of Henderson Waterway, close to its confluence with Cashmere Stream. Both of these areas have high shading due to extensive and established riparian plants, which are likely to be important contributors to the persistence of these species in these areas. Where it is ecologically sensible to remove exotic species (e.g. willow trees) this should be done carefully, with individual trees being removed and replaced over time. The in-stream conditions could be left relatively intact, with the addition, or inclusion, of structures to improve habitat complexity.
- More focussed surveys of kēkēwai and kākahi prior to realignment works may be justified, particularly so that where populations of these species occur either alternative 'softer' approaches are developed and employed, or focussed, species-specific salvage efforts are used during construction works.
- In-stream habitat heterogeneity (including availability of a variety of habitats such as macrophyte beds, woody debris, log jams, leaf packs, and stable undercut banks) is essential for maintaining the health of a waterway and supporting diverse macroinvertebrate and fish communities. A diversity of in-stream habitat can be rare in rural and semi-urban waterways, and particularly in those that are regularly maintained for flood conveyance purposes.
- Where space constrains the ability to realign waterways, regrade banks, and improve sinuosity (e.g. landownership reduces the footprint available for waterway realignment), alternative measures (interim or longer term) could be used to enhance steep banks. For example, much of the length of Henderson Waterway is constrained by Hendersons Road (true left) and privately-owned land (true right). The CCC would need to purchase land on the true right in order to greatly improve the waterway's sinuosity. If this is not possible, structures such as large logs / tree stumps or concrete blocks and open-

ended pipes may be fixed into the banks (below the water level) to provide a range of habitat and stable undercut banks for fish, kēkēwai and other aquatic fauna. This could be done in such a way so as to avoid markedly altering flood conveyance and capacity of these waterways.

- Overall, it is recommended that there be no net loss of freshwater habitat as a result of the realignment and naturalisation programme for these waterways.
- Development of a monitoring programme to monitor the success of any realignment and enhancement works, and evaluate the need for any additional improvements.

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Appendix 1: Site photos from November 2016

Site 1: Dunbar Waterway – upstream, November 2016

Site 2: Dunbar Waterway – downstream, November 2016

Site 3: Days Waterway – upstream, November 2016

Site 4: Days Waterway – downstream, November 2016

Site 5: Hendersons Road Branch Drain, November 2016

Site 6: Henderson Waterway – upstream, November 2016


Site 7: Henderson Waterway – mid, November 2016


Site 8: Henderson Waterway – downstream, November 2016

Appendix 2: Actual and potential barriers

A1: Perched culvert under driveway, Henderson Waterway, 150 m upstream of Site 6; Inanga observed in pool below culvert.

A2: Perched culvert along Dunbar waterway.

A3: Perched culvert along Dunbar Waterway, at Sparks Road, upstream of Site 2.

A4: Perched culvert along Dunbar Waterway, downstream of Sparks Road, upstream of Site 2.

P1: Debris gate does not reach below water level, but could be a barrier to fish passage when debris builds up.

P2: Timber cross beam may be a barrier to fish passage at times of low flow; Hendersons Road Branch Drain, approximately 20 m downstream of Site 5.

P3: Perched concrete sill, which may be a barrier to fish passage during periods of low flow, downstream of Site 4 in Days Waterway.

P4: Road culvert, upstream of Sparks Road, may collect woody debris and litter, which may be a barrier to fish passage.

P5: Culvert on lower Henderson Waterway, has potential to be a barrier in both high and low flows.

File Ref: C16118_003_A3L_StreamBarriers.mxd

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0 120 m
1:6,500 @ A3

Data Sources:
Cadastre and Aerial sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 3.0 NZ licence."
Projection: NZGD 2000 New Zealand Transverse Mercator

Legend
- Actual barrier (A1-A4)
- Potential barrier (P1-P5)
- Sampling Sites
- Piped waterway
- Open waterway

AQUATIC ECOLOGY

In-stream Barriers

Date: 13 December 2016 | Revision: 0

Plan prepared for CCC by Boffa Miskell Limited

Project Manager: **tanya.blakely@boffamiskell.co.nz** | *Drawn:* BMc | *Checked:* TBl

Appendix 3: Similarity Percentages (SIMPER)

SIMPER

Similarity Percentages - species contributions

Dunbar & Days Waterways
Average dissimilarity = 70.75

Species	Group Dunbar Av.Abund	Group Days Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus antipodarum	1517.50	829.00	16.59	1.86	23.45	23.45
NEMATODA	3.00	768.00	13.08	0.92	18.49	41.94
Copepoda	1.00	840.00	11.93	0.86	16.87	58.81
Orthocladiinae, excl. Corynoneura	2.50	834.00	11.91	0.95	16.83	75.64
Sphaeriidae	261.00	33.50	3.82	0.99	5.39	81.03
Ostracoda	339.00	248.50	3.71	1.07	5.24	86.27
Paracalliope fluviatilis	256.00	0.00	3.69	1.01	5.21	91.48

Dunbar & Hendersons Road Branch Waterways
Average dissimilarity = 79.82

Species	Group Dunbar Av.Abund	Group Hendersons Road Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope fluviatilis	256.00	2800.00	44.07	3.72	55.21	55.21
Potamopyrgus antipodarum	1517.50	187.00	21.30	1.21	26.69	81.90
Ostracoda	339.00	80.00	4.82	0.84	6.03	87.93
Sphaeriidae	261.00	10.00	4.65	0.89	5.82	93.75

Days & Hendersons Road Branch Waterways
Average dissimilarity = 89.94

Species	Group Days Av.Abund	Group Hendersons Road Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalliope fluviatilis	0.00	2800.00	38.20	8.49	42.47	42.47
NEMATODA	768.00	0.00	11.27	0.77	12.53	54.99
Copepoda	840.00	0.00	10.50	0.71	11.68	66.67
Orthocladiinae, excl. Corynoneura	834.00	1.00	10.49	0.78	11.67	78.34
Potamopyrgus antipodarum	829.00	187.00	9.98	0.74	11.09	89.43
Hudsonema amabile	0.00	169.00	2.31	8.49	2.56	92.00

Dunbar & Henderson Waterways

Average dissimilarity = 72.14

Species	Group Dunbar Av.Abund	Group Henderson Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus antipodarum	1517.50	10000.00	50.03	6.42	69.35	69.35
Paracalliope fluviatilis	256.00	2091.00	10.92	2.32	15.14	84.49
Ostracoda	339.00	1163.00	4.81	1.15	6.67	91.16

Days & Henderson Waterways

Average dissimilarity = 84.25

Species	Group Days Av.Abund	Group Henderson Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus antipodarum	829.00	10000.00	49.41	16.99	58.65	58.65
Paracalliope fluviatilis	0.00	2091.00	11.37	2.85	13.49	72.15
Ostracoda	248.50	1163.00	4.84	1.20	5.75	77.90
Copepoda	840.00	0.00	4.39	0.91	5.21	83.10
Orthocladiinae, excl. Corynoneura	834.00	67.00	4.19	0.99	4.98	88.08
NEMATODA	768.00	219.00	3.98	1.11	4.72	92.80

Hendersons Road Branch & Henderson Waterways

Average dissimilarity = 72.36

Species	Group Hendersons Road Av.Abund	Group Henderson Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus antipodarum	187.00	10000.00	54.68	22.62	75.56	75.56
Ostracoda	80.00	1163.00	5.90	1.32	8.16	83.72
Paracalliope fluviatilis	2800.00	2091.00	4.12	1.11	5.70	89.42
Sphaeriidae	10.00	503.67	2.72	2.25	3.76	93.18