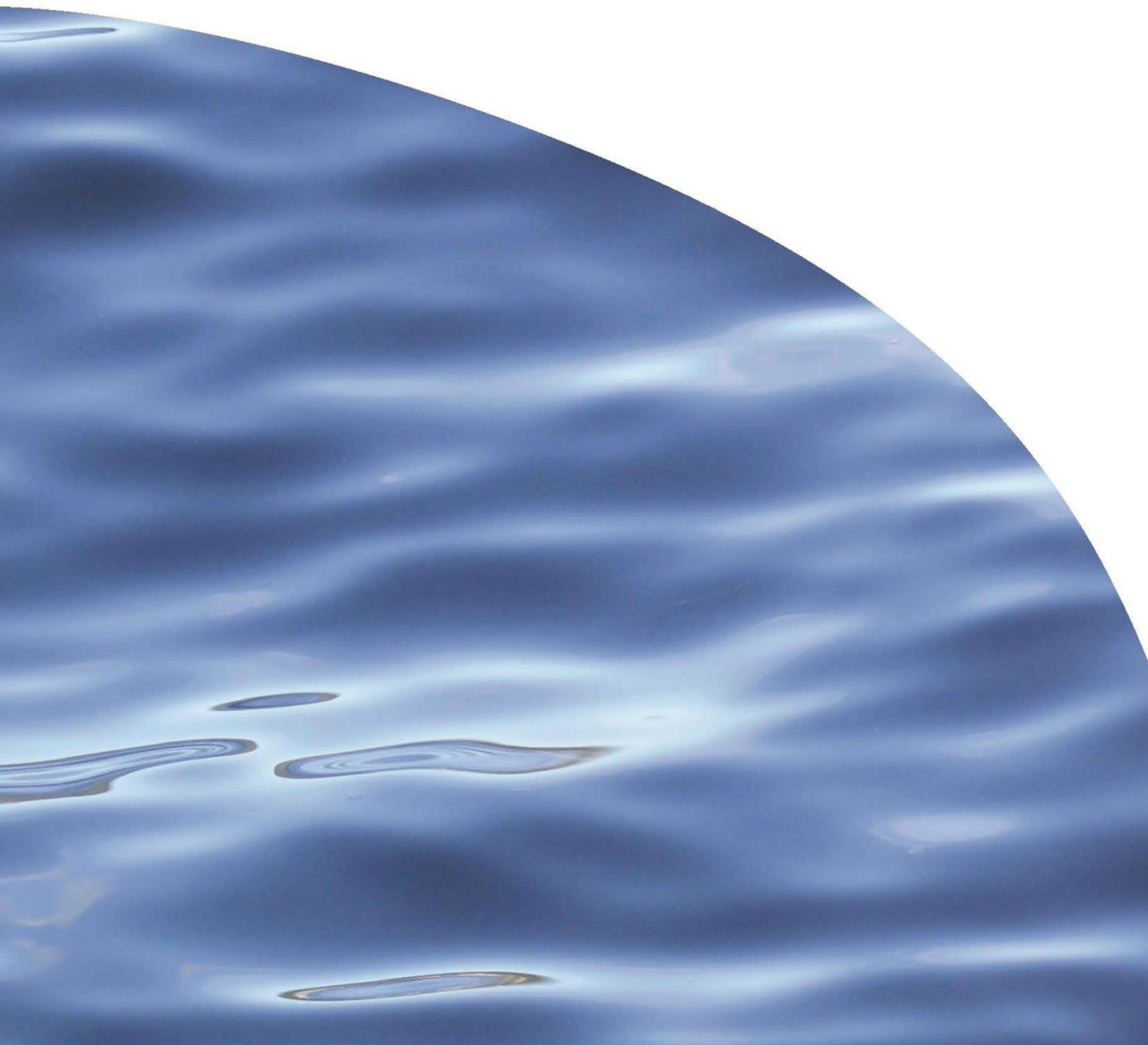# CAWTHRON
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REPORT NO. 3574

THE RELATIONSHIP BETWEEN INVERTEBRATE DRIFT AND FLOW IN THE MANUHERIKIA RIVER

THE RELATIONSHIP BETWEEN INVERTEBRATE DRIFT AND FLOW IN THE MANUHERIKIA RIVER

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1. INTRODUCTION

This report presents a study of the relationship between aquatic invertebrate drift and flow in the lower Manuherikia River. The study supports an assessment of ecological effects of flow management scenarios for the Manuherikia River in the current review of the Regional Plan: Water for Otago. The main aim of the Manuherikia River aquatic invertebrate drift sampling study was to obtain empirical evidence for whether the concentration and flux (rate) of drifting invertebrates declines with flow reduction.

Benthic aquatic invertebrates enter the water column and begin drifting via passive or active mechanisms. Passive drift occurs when invertebrates are accidentally entrained into the water column by near-bed shear stress (related to water velocity and turbulence). Particle transport theory and process-based transport modelling predicts that the concentration and flux of fine particles (including invertebrates) should decline with flow reduction. However, the empirical evidence for drift concentration declining with flow reduction is equivocal; some studies from drift sampling in New Zealand and overseas rivers are supportive, others are not. This is not surprising given that *active* (behavioural) drift can obscure the signal of flow-related passive drift. Invertebrates enter the drift actively (i.e. volitionally) for various reasons, including to find more suitable habitat, escape predators, and emerge (to complete their lifecycles). Very low flows can cause invertebrates to actively drift to escape desiccation and to find more suitable faster flowing habitat. Active drift can be highly variable in space and time, usually peaking at dusk and to a lesser extent at dawn. For this reason, it makes sense to sample drift during daylight hours when attempting to isolate the influence of flow on passive, background, drift. Nevertheless, pulses of active drift may occur due to emergence at any period in the day or in response to declining habitat quality.

Understanding whether drift concentration and rate declines with flow reduction is relevant to assessing the effects of flow abstraction on dispersal of invertebrates as well as food supply for drift-feeding fishes, such as introduced trout and some native galaxiids. Once a regression relationship between flow and drift concentration, or flow and drift flux, is established, it can be used to estimate the percentage reduction in instantaneous drift food supply that a flow allocation rate represents, relative to the drift concentration or flux sustained by a reference flow in the absence of allocation (i.e. for X percentage flow reduction, caused by an allocation being taken, drift concentration or flux (rate) declines by Y percent).

In addition to the primary aim of obtaining empirical evidence for whether aquatic invertebrate drift responds to flow, the study also provided information on benthic invertebrate density, community and size structure and how these responded to flow variation and periphyton in the lower Manuherikia River.

2. METHODS

2.1. Invertebrate drift sampling

Drift samples were collected at 15 locations (3 locations on each of 5 cross-sections) in a reach of the Manuherikia River 1-2 km below Chatto Creek (by Olrig Station) on six sampling occasions (flows)—30 November 2019, 1 December 2019 and 13,16,18, 22 January 2020 (Figure 1). Our intention was to sample on five occasions over a single flow recession (i.e. November/December 2019) to determine the relationship between flow and drift concentration and flux (rate). However, floods after the second sampling occasion (after 1 December) forced us to delay further sampling until January, when we were presented with another suitable flow recession. When we commenced sampling on the January flow recession, flow had declined further than was ideal for characterising the drift-flow relationship in the Manuherikia River. The last four sampling occasions were at very low flows at the tail of a long flow recession (Figure 1).

The cylindrical drift samplers were 0.150 m in diameter (0.018 m² cross-sectional area) and had 0.5-mm mesh. This mesh size ought to retain invertebrates > 3 mm long, based on approximate invertebrate width–length relationships. Water velocity through the samplers was measured by mechanical counter, propeller flow meters suspended inside the PVC collar. Samplers were attached by bridle to Y-section steel stakes in water < 1 m deep.

Drift samplers were regularly inspected for clogging, which proved to be inconsequential. Volumes of water sampled by the drift nets were estimated as the product of sample cross-sectional area, sample duration and water velocities estimated from the sampler current meters.

2.2. Benthic invertebrate sampling

Benthic sampling was undertaken to determine benthic invertebrate community taxonomic and size structure during the recession over which invertebrate drift was collected. Benthic invertebrate samples were collected once on the first (November-December) recession, and three times during the second (January) recession (Figure 1). Fifteen benthic samples were collected on the first recession and 15 at the start of the second recession. On the first recession three of the samples were collected from one cross-section on 31 November, and the rest were collected on 2 December from four other cross-sections. On the second recession all fifteen samples were collected on the same day, i.e. 15 January 2020 (Figure 1). On each recession three benthic invertebrate samples were collected upstream of the 5 drift sampling cross-sections.

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A further six samples were collected near the end of the drift sampling on the second recession (21 January 2020) at cross-sections 3 and 5 (3 samples from each cross-sections). Finally, nine samples were collected one month after the drift sampling was completed (21 February 2020) at 3 cross-sections (Figure 1).

Benthic invertebrates were sampled with a 0.1 m² Surber sampler (0.5-mm mesh). Samples were positioned roughly evenly out from the true right bank as far as the thalweg or until the water become too fast and deep to hold station and sample effectively.
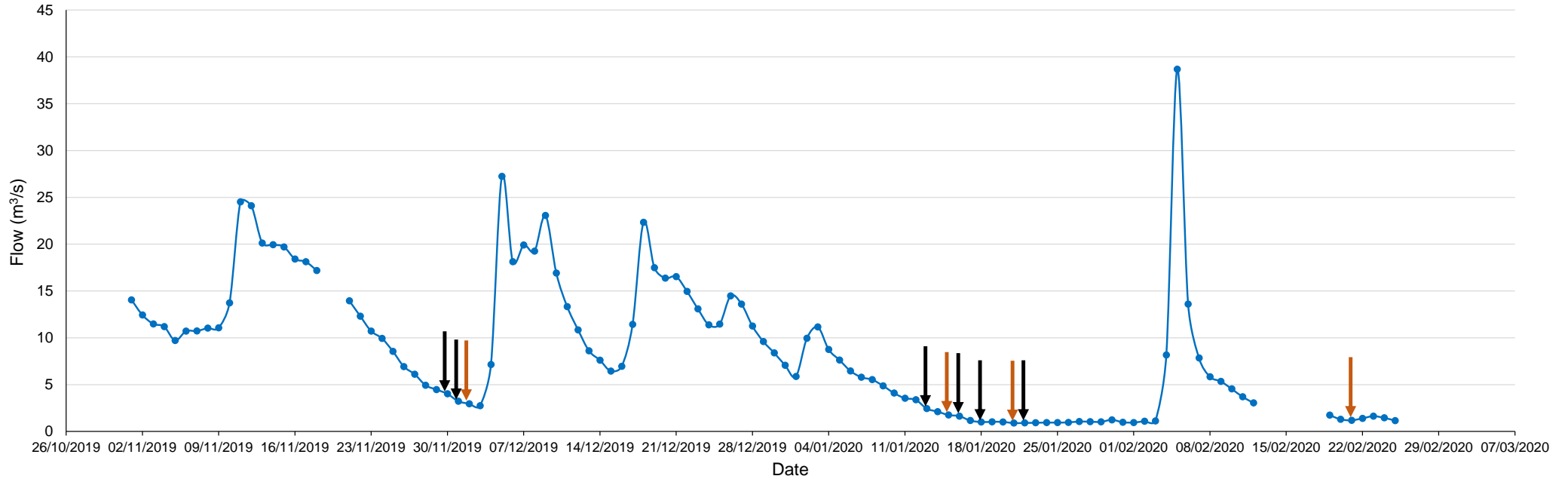
Figure 1.   Hydrograph of mean daily flow in Manuherikia River in the Olrig Station invertebrate sampling reach from 1 November 2019 to 25 February 2020. Arrows indicate drifting invertebrate (black) and benthic invertebrate (orange) sampling occasions. Flow was estimated as the sum of flow in the Manuherikia above Chatto Creek (from the Manuherikia at Chatto Creek upstream flow recorder) and flow in Chatto Creek at confluence (from a flow recorder installed in Chatto Creek by ORC for the Manuherikia project) (data and information supplied by Lu Xiaofeng, hydrologist, Otago Regional Council).

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2.3. Invertebrate sample processing

Macroinvertebrate samples were processed following a modified version of Protocol P3 (Stark et al. 2001). The samples from each location were washed through 2.0-mm and 0.5-mm mesh sieves to facilitate processing. The larger sample portion was placed into a white sampling tray and the smaller into a series of Petri dishes. Invertebrates were removed from the tray and placed in Petri dishes for taxonomic identification and size classing. Each Petri dish was placed on top of a 3 x 3 mm grid attached to the base plate of the microscope to facilitate size-classing the invertebrates into 3-mm body length classes (3–6 mm, 6–9 mm and > 9 mm). Invertebrates were identified to species level where practical, or coarser taxonomic level, and counted. We excluded pupae, because they actively drift (i.e. transitioning from the aquatic to terrestrial adult life phase of the life cycle is a form of behavioural drift).

2.4. Drift data analysis

2.4.1. Data summarising and transformation

Water velocities fell below the calibrated range for the propeller current meters during the drift sampling occasions at the four lowest flows in January. This meant we were unable to calculate drift concentrations for those samples because we could not accurately estimate sampled water volumes. Hence, we confined our analysis of all samples to drift counts converted to drift rates (no. / hour). To do this we calculated drift rate (invertebrate counts divided by duration sampled) for each drift sampler location[1].

The drift data from the two recessions are not directly comparable because drift rates are influenced by benthic density and which will have changed over the one and a half months between the two recessions. However, if drift concentration and rate decline with flow reduction we would expect to see evidence for this independently in the datasets for both recessions. All samples in the analysed time (flow) series were taken from the same locations on all sampling occasions. Hence, the drift rates are comparable between occasions (flows) within locations and within recession.

Because the drift rates estimated for each sampling location were not independent between sampling occasion and between recessions we standardised the drift rates per recession, calculating the drift rate at each location during a recession as a proportion of the total drift rate summed over all sites in that recession.

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[1] 5 cross sections with 3 drift samplers on each cross section = 15 sample locations in total.

2.4.2. Modelling

For the drift versus flow analysis, invertebrate drift rates were $\log_2$-transformed to linearise the relationship and reduce heteroscedasticity. We tested the log-transformed invertebrate drift rate values for normality with an Anderson-Darling normality test (Thode 2002).

We used linear regression models to analyse the relationship between invertebrate drift rate and mean flow of the river at the time of sampling. We modelled the relationship between standardised drift rate and flow for the following size classes (all taxa combined), (1) greater than 3 mm, and (2) greater than 6 mm, (3) 3-6 mm and (4) 6-9 mm. We included recession in the models as a fixed effect, to account for the two sampling periods.

In addition, we tested whether standardised drift rate versus flow relationships were exhibited by different taxonomic groups. To do this, we divided the data into eight taxonomic groups: (1) leptophlebiid mayflies (mainly *Deleatidium* spp.), (2) non-biting Diptera (Chironomidae—mainly Orthocladiinae), (3) biting Diptera (*Austrosimulium* spp.—black flies), (4) Elmidae, (5) net-spinning hydropsychid caddisflies (*Aoteapsyche* spp.), (6) free living hydrobiosid caddisflies, (7) horny-cased conoesucid caddis flies (*Olinga* spp.), (8) other cased caddis (*Hudsonema* sp.) and (9) sandy/stony-cased conoesucid caddisflies (*Pycnocentria* sp. and *Pycnocentrodes* sp.).

3. RESULTS AND DISCUSSION

3.1. Benthic invertebrate densities and size structure

Benthic densities were highest during the mid-summer months (January and February), (Figures 2 and 3). In the absence of density-dependent mortality, benthic densities will increase over time as flows remain stable, as was shown between the 15 and 22 January sampling occasions (Figures 2 & 3). The reasons for the increase in density will in part be due to concentration of invertebrates, resulting from contraction of the available habitat area (i.e. reduction in river width as flows decreased), recruitment over the summer period, and periphyton proliferation favouring species that prefer high algal biomass (extensive filamentous algal biomass were noted over the January flow recession; photographed on 22 January 2020 — see Appendix 1).

The number of small invertebrates (3–6 mm) was highest during the mid-summer period when aquatic insect recruitment (through hatching of larvae) is usually greatest (Figure 3). Invertebrate densities on each sampling occasion comprised mainly the

common mayfly, *Deleatidium*, the small non-biting midge larvae Othocladiinae and the net-spinning caddis *Aoteapsyche* (Figure 2). The contribution of Orthocladiinae rose and fell with duration of stable flows and changes in algal biomass (which was lowest after the 5 February 2020 fresh). The increase in *Aoteapsyche* densities between the January sampling occasion may have been due to an increase in algal biomass and associated seston (drifting algal particles) providing more food for filter feeding, countering the reduction in flow and water velocities that would otherwise reduce that rate of drifting seston and associated habitat suitability for net-spinning caddis (Jowett 2000; Shearer et al. 2015). For example, Harding (2008) found *Aoteapsyche* larvae ingested a higher proportion of filamentous algae and diatoms below lake outlets with slower water velocities (< 0.2 m/s).

Floods and freshes ('flushing flows') about 3 or more times the median flow flush fine sediment, periphyton and other aquatic vegetation (Biggs & Close 1989; Clausen & Biggs 1997). Smaller freshes may reduce macroinvertebrate abundance to a lesser extent, preferentially flushing taxa associated with algae (periphyton), and recovery is usually faster (in the order of weeks) than following large floods. An example of this was shown in the February 21 sampling, where a small fresh prior to sampling on 5 February (see Figure 1) reduced invertebrate densities.

Following distribution of the photographs showing algal proliferation in the study reach during the January 2020 flow recession, concern was raised by Otago Fish and Game Council staff over the possibility of high algal biomass in the Manuherikia River causing dissolved oxygen depletion and adversely affecting life-supporting capacity. Dissolved oxygen was not measured during our study. However, based on our benthic invertebrate data, we found no evidence to suggest that dissolved oxygen depletion was sufficient to cause acute (lethal) effects and a subsequent reduction of benthic invertebrate densities. Our data were not sufficient to assess the possibility of chronic or sub-lethal effects of potentially low dissolved oxygen levels.
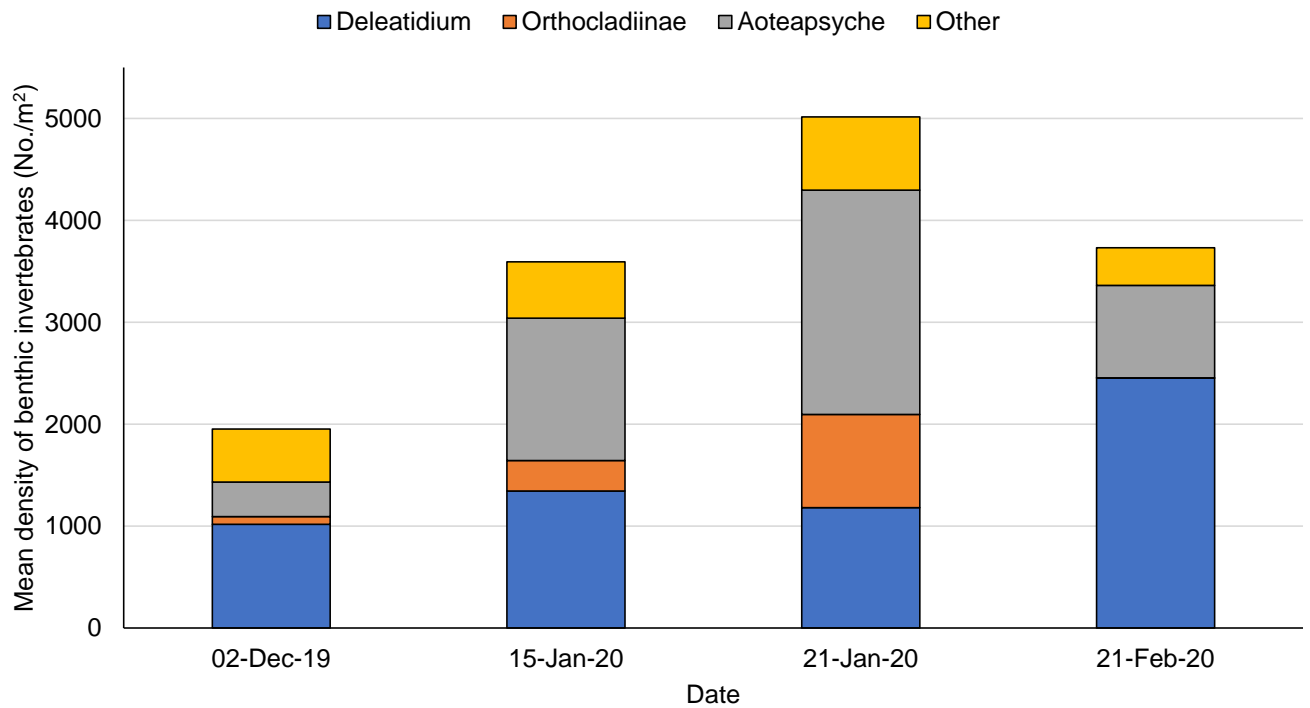
Figure 2.   Mean densities (no./m^2) of the three main benthic invertebrate groups (i.e. the common mayfly *Deleatidium*, the midge larvae Orthocladiinae and net-spinning caddisfly *Aoteapsyche*) and all other taxa grouped together.
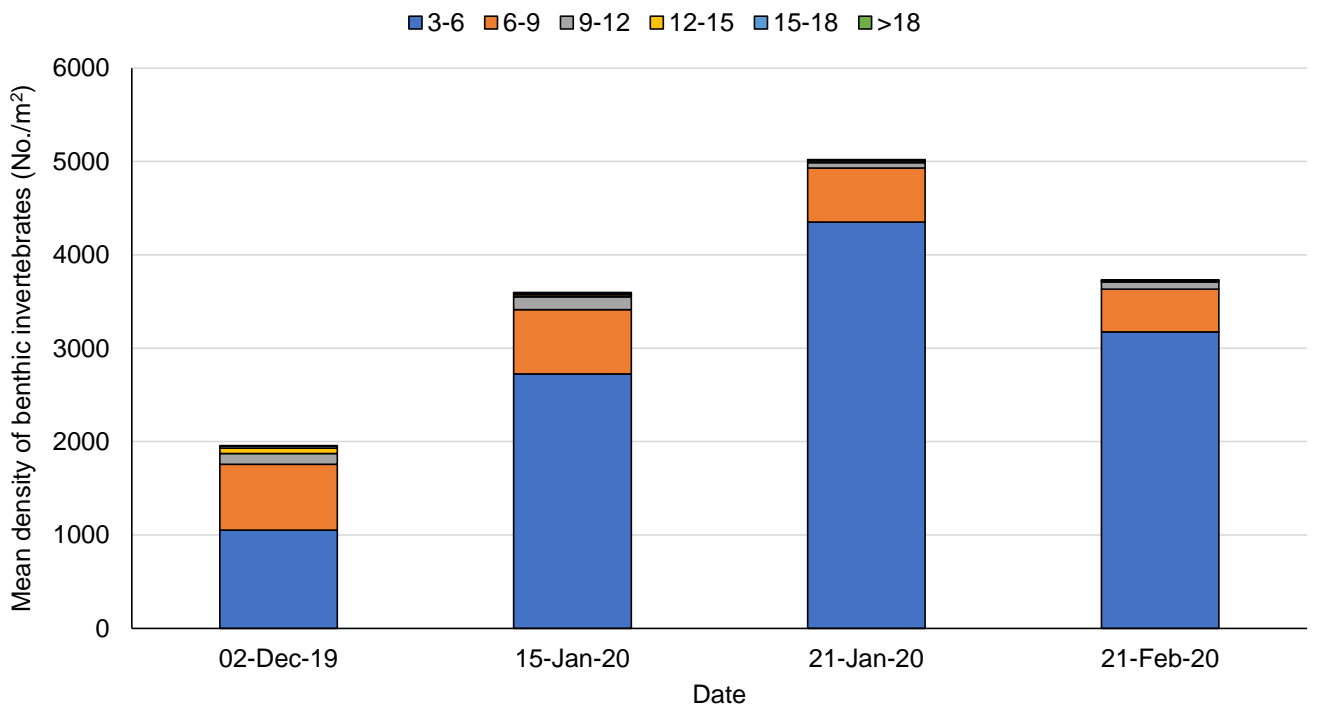

Figure 3.   Mean benthic invertebrate densities (no./m^2) by 3 mm size class, with taxa greater than 18 mm grouped together.

3.2. Invertebrate drift versus flow relationship

Figures 4 and 5 show the relationship between drift rate and flow for invertebrates greater than 3 and 6 mm, respectively. When interpreting these figures bear in mind that the results for the two flow recessions are independent. Therefore, we are looking for trends in standardised drift rate versus flow over the two highest flows sampled (first recession) and the four lowest flows samples (second recession) and consistency in any trends between the recessions. The figures indicate no apparent trends between standardised drift rate and flow for either recession. This is confirmed by the regression modelling (> 3 mm regression $R^2 = 0.004$, $F_{2,85} = 1.181$, $P = 0.312$, flow co-efficient $P = 0.128$; > 6 mm regression $R^2 = 0.194$, $F_{2,76} = 10.37$, $P < 0.001$, flow co-efficient $P = 0.381$). The significant regression for the > 6 mm standardised drift rate versus flow relationship was driven by a difference in the mean standardised drift rate between the recessions (recession co-efficient $P = 0.005$) and not by flow (i.e. there were proportionately more large invertebrates (> 6 mm) drifting in the first recession than the second, but there was no significant relationship between standardised drift rate and flow within either recession).
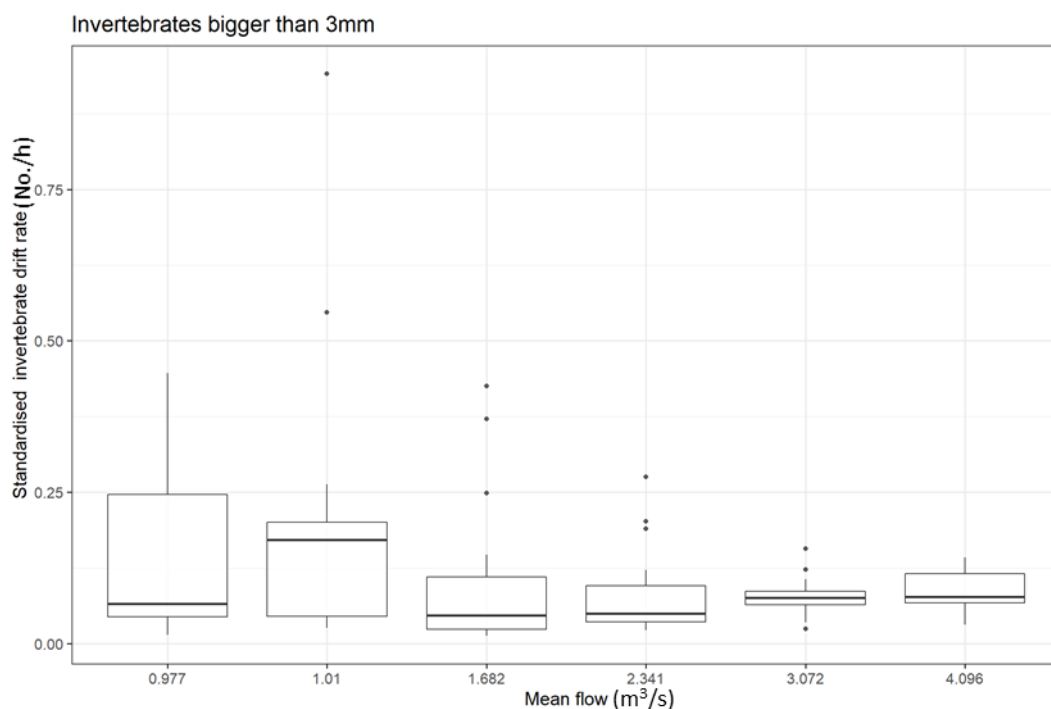

Figure 4.   Box and whisker plots of standardised drift rates (invertebrates > 3mm) for all six flows sampled in the Manuherikia River. The two highest flows are the November / December 2019 sampling occasions, the four lowest are the January 2020 sampling occasions. For each flow the graph displays the minimum, maximum (whiskers), median (bold horizontal line), first and third quartiles, and outliers (dots).
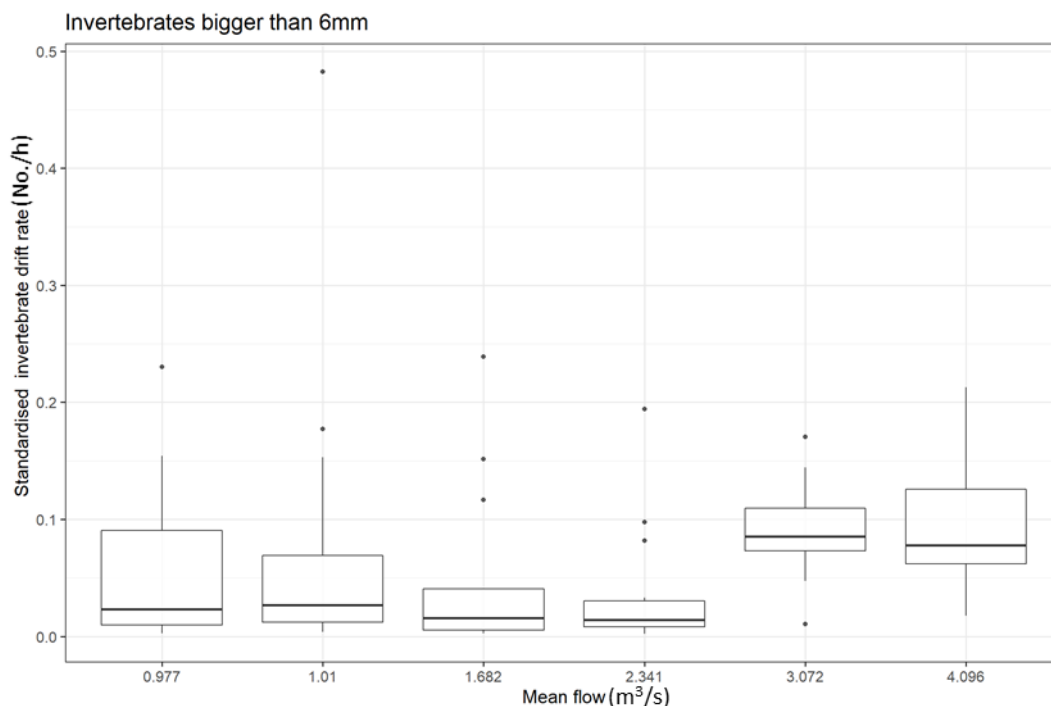
Figure 5.   Box and whisker plots of standardised drift rates (invertebrates > 6mm) for all six flows
sampled in the Manuherikia River. The two highest flows are the November/December
2019 sampling occasions, the four lowest are the January 2020 sampling occasions. For
each flow the graph displays the minimum and maximum (whiskers), median (bold
horizontal line), first and third quartiles (box), and outliers (dots).

Given that drift rate did not decline significantly with flow reduction over either flow
recession sampled we can infer that drift concentration must have been increasing
with flow reduction. This inference can be made because drift rate (no./s) is the
product of drift concentration (no./m³), water velocity (m/s) and cross-sectional area
(m²) sampled, the latter being the area of the drift sampler—which is a constant. As
flow declines, mean water velocity over a reach, or at any point in a reach, also
declines. Hence, drift rate should decline with flow reduction if drift concentration is
constant or declines. When drift rate remains constant with flow reduction, drift
concentration must be increasing to counteract the decline in mean velocity. Mean
water velocity is estimated to have declined by about 13% and 36% over the flow
ranges (4.096–3.072 m³/s and 2.341–0.977 m³/s) sampled for drift in the first and
second flow recessions, respectively (Figure 6). Given that passive entrainment of
benthic invertebrates from the riverbed also declines with flow reduction, owing to
lower near-bed shear stress (Hayes et al. 2018), invertebrates must be actively
drifting when drift rate remains constant with flow reduction. Invertebrates may
actively drift to emerge, avoid predators or to find more suitable habitat in response to
declining habitat quality—such as can occur at low flow. On the other hand, drift
concentration, and rate, is also expected to increase with increasing benthic
invertebrate density (Shearer et al. 2003; Weber et al. 2014). There was insufficient
time for benthic density to increase during the first drift sampling period (2 days).

Benthic density did increase over the second sampling period (Figure 6). Some of this increase will be due to population accrual and to benthic invertebrates concentrating as the wetted width decreased (16% reduction in wetted width over the 9-day second drift sampling period (Figure 6)).
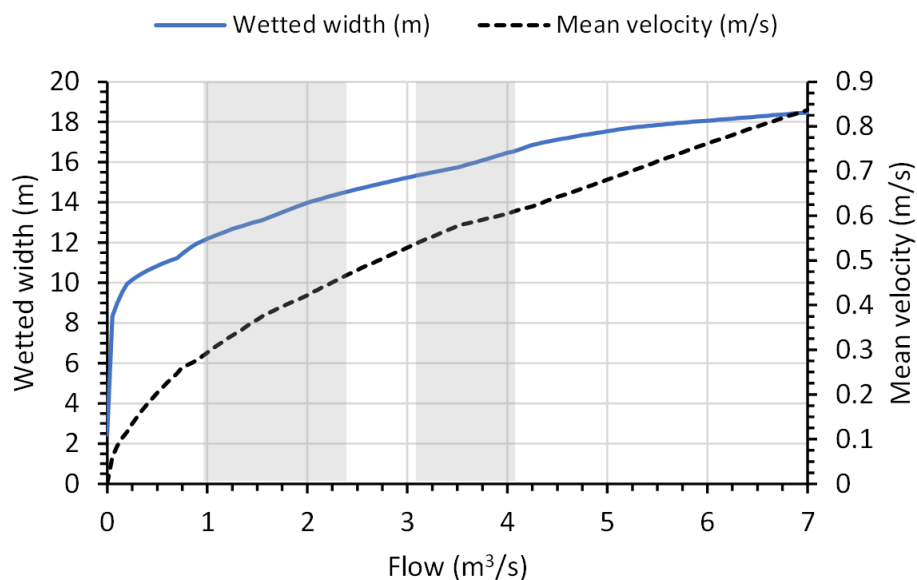

Figure 6.   Relationships between flow and wetted width and mean velocity predicted by hydraulic-habitat modelling undertaken in the modelling package SEFA (System for Environmental Flow Analysis) by Richard Allibone in a reach in the Galloway segment of the Manuherikia River. Grey-shaded boxes indicate the flow ranges over which drift sampling was conducted within the two flow recessions.

The three invertebrate taxa most consistently collected in the Manuherikia River drift were chironomids (orthoclads) (non-biting Diptera), *Deleatidium* (common mayfly) and *Aoteapsyche* (net-spinning caddisfly) (Figure 7). *Deleatidium* was the most abundantly caught taxa on the first recession, whereas Chironomidae dominated on the second recession. *Deleatidium* and chironomids are both collector browsers that feed on algae and detritus, although *Deleatidium* are often more exposed to water currents because they are more active in searching for food than the smaller chironomids that tend to create burrows. *Aoteapsyche* are net-building filter-feeders that rely heavily on strong currents to transport their food (fine particulate organic matter). None of the taxa examined, including the above three, showed a statistically significant relationship between standardised drift rate and flow for either recession ($P > 0.10$).
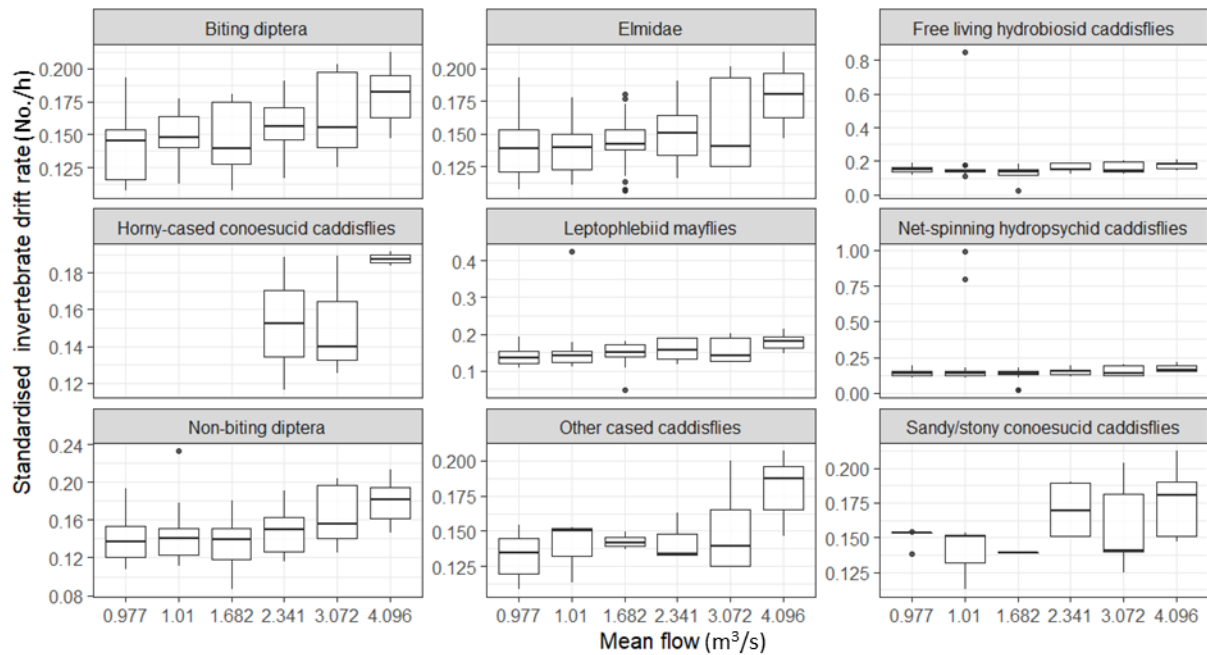
Figure 7.   Box and whisker plots of standardised drift rates (invertebrates > 3mm) for nine taxa on all six flows sampled in the Manuherikia River. The two highest flows are the November/December 2019 sampling occasions, the four lowest the January 2020 sampling occasions. For each flow the graph displays the minimum and maximum (whiskers), median (bold horizontal line), first and third quartiles (box), and outliers (dots).

In summary, process-based drift transport modelling has shown that theoretically the concentration (no./m³) and rate of passively drifting aquatic invertebrates should decline with flow reduction (Hayes et al. 2018). Moreover, there is some empirical evidence for this from New Zealand and overseas rivers (Kennedy et al. 2013; Hayes et al. 2018, 2020). Even if drift concentration was constant (i.e. did not decline) with flow reduction, drift rate ought to decline simply because average water velocity declines (given that drift rate is the product of drift concentration, water velocity and cross-sectional area (i.e. of the samplers or an entire cross-section)). The fact that we found no evidence for drift rate declining with flow reduction in the Manuherikia River study reach indicates that drift concentration must have increased with flow reduction. This suggests that variability in active drift was dominating that of passive drift over the flow range sampled.

4. CONCLUSIONS

1. We found no evidence for a relationship between the drift rate of > 3 mm and > 6 mm aquatic invertebrates and flow in the Manuherikia River study reach.

2. Nor did we find evidence for a relationship between drift rate and flow for the three most abundantly collected taxa (chironomids (non-biting flies), *Deleatidium* (common mayfly) and *Aoteapsyche* (net-spinning caddisfly).

3. Regarding flow management scenarios being considered for the Manuherikia River in the review of the Regional Plan: Water for Otago; the results of this study do not support the assumption that drift rate declines with flow reduction for flows between 1 and 4 m/s.

4. There was no reduction of benthic invertebrate densities associated with periphyton proliferation during a prolonged flow recession sampled in January 2020. Therefore, it is unlikely that periphyton proliferation observed at low flow during our study caused dissolved oxygen depletion to levels that might be lethal to invertebrates.

5. ACKNOWLEDGEMENTS

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7. APPENDIX

Appendix 1. Selection of photographs taken on 20 and 21 January 2020 of extensive filamentous algal growth in the Manuherikia River invertebrate drift sampling reach (near Olrig Station). Photos were taken by Ross Dungey (Ross Dungey Consulting Ltd).